Government of the Province of Alberta

REPORT

on the

ALBERTA BITUMINOUS SANDS

by

S. M. BLAIR

EDMONTON
ALBERTA
CANADA

DECEMBER
1950

#62

THE DEVELOPMENT OF THE ALBERTA BITUMINOUS SANDS

by

S. M. BLAIR

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and

Universal Oil Products Company

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430
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S. M. BLAIR

December 12th, 1950.

Sirs -

I submit herewith the Report as requested on the Bituminous Sands of Alberta.

The Report commences with the raw material in place and continues with the economic and technical aspects of producing finished marketable oils from this immense resource.

I remain,

Yours faithfully,

S. M. Blair

PROFESSIONAL ENGINEER - ALBERTA
S. M. BLAIR
Licence valid until
Jan. 2nd 1952
LICENSED TO PRACTISE

The Honorable D. B. MacMillan,
Minister of Public Works,

The Honorable N. E. Tanner,
Minister of Mines and Minerals,

The Honorable J. L. Robinson,
Minister of Labor,

EDMONTON, Alberta.

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Acknowledgments

The preparation of this Report has been made possible by the extremely generous co-operation given by everyone concerned. The members of many of the Departments in the Federal and Provincial Governments, and the Executives, Scientists, Engineers and Economists associated with Industry have given extensively of their time and liberally presented the results of their research to aid the Survey.

The assistance of the Geological Division and the Mines Branch at Ottawa, the National Research Council, the Alberta Research Council, and the Alberta Oil Sands Project Committee require special mention.

It has only been through the use of their findings when co-ordinated with the experience of parallel work in Industry that it has been possible to complete the Survey at the present time.

The full co-operation of the Bureau of Mines, Washington, has also been greatly appreciated.

Foreword

This report is compiled in the form of three Chapters with a summary at the end of each.

The first Chapter deals with the deposit of raw material and briefly describes the components and their relationship.

The second Chapter reviews the costs and the methods available for winning the bitumen, converting it to a useful oil and delivering it to the market. This Chapter is briefly referred to as "The Tools for Evaluation".

Chapter III compiles the costs for the selected program. It also evaluates the products made and reviews the direct production costs in the light of the estimated realizations.

Two brief sections are presented prior to Chapter I. In the first of these the Overall Conclusions from the Survey are listed. In the second the Recommendations are given of the work and procedure which is considered necessary.

Conclusions

1. The Bituminous Sands can be mined and the Bitumen processed by established methods. The product is a distillate. The distillate can be in the form of a desulphurized blend of gasoline and a gas oil similar to No. 2 grade fuel. The blend resembles a medium gravity crude of low sulphur from which the heavy fuel oil components have been removed.

2. The production can be attained by a sequence of operations, each step of which is considered to be sufficiently proven, both technically and economically, to permit the determination of reasonably safe capital and operating costs. The evidence available in support of each step is from proven commercial operations and the results of test plant runs to accumulate specific data on the material.

3. The total production has been evaluated directly in bulk on major markets, and it has also been evaluated from the sum of the values of its components after final processing. It is estimated that the total product would have a value of at least $3.50 per barrel at the Great Lakes terminal of the Canadian pipe line.

4. The Estimated total Direct operating cost is $3.10 per barrel for the production and delivery of the oil. This includes all associated field costs and administration, but does not include an allowance for interest on the capital or profit.

5. The difference of 40¢ per barrel between the estimated value and the direct operating costs could yield between 5 and 6 percent on the capital involved exclusive of that required for transportation which has been considered on a direct profit earning basis.

6. It is possible that further study and investigational work will establish that the 40¢ per barrel differential can be materially increased by proof of possible reductions in production and associated costs, and possibly even more by ensuring the attainment of a higher valued product.

7. The magnitude on which the operations are carried out is particularly important for this material. The capacity of any development must be relatively high in order to secure efficient transportation and handling costs. A basic commercial attraction at present, however, is the ease of proving adequate raw material for almost any scale of operation. This survey is based on a throughput of 20,000 barrels per day. Larger throughput could attain significant reductions in cost, but appreciably smaller scale operations, with the processing used, will be more costly.

8. The economic production of oil in the area of the Bituminous Sands originally appeared to be opposed by inherently high transportation costs. High quality distillates as can be made from the Bitumen command a premium market price and will not encounter transport costs that are such a big percentage of the total value as is the case with normal crude oil.

9. Bitumen oil and mineral crude oil resources in the same general area may complement one another's development. The pipe line from Alberta to the major markets of the East has enhanced the possibility of bitumen production on the scale needed for efficient operation. At the same time, equipment installed for the recovery of bitumen oil could provide a means of proving up local low grade mineral oils which would not in themselves justify the capital expenditure required for their development.

10. Government has thus far established something of the magnitude of the deposit and has developed fundamental methods of oil recovery. For the future Government could provide Industry with essential technical data on pertinent operations and with possible schedules for commercial development.

11. The practice of bracketing this Bituminous Sand with oil shale and coal as three potential sources of commercial oil is incorrect and very misleading. The oils that will be made from the bitumen do not have technical nor economic resemblance to shale or coal oils.

12. The co-operation which has been given this survey by all Government Departments (both Federal and Provincial) and by Industry has been magnificent. The subject is so vast and important that full co-ordination is required to secure the desired progress.

Recommendations

The co-ordination of the results from Research and Industry indicate that the development of this immense resource is now entering the stage of possible commercial development.

At this stage the phases to which recommendations are directed fall into two general groups. The one group pertains to General Policy while the other is on Specific Technical and Economic work requiring attention. Since some of the recommendations on Policy are directly related to the immediate work to be done, the Technical program is dealt with first.

RECOMMENDATIONS ON TECHNICAL WORK

With the proving up of so many links in the chain of processes for dealing with the Bituminous Sand it is particularly difficult at the present time to limit the recommendations. There is a vast amount of technical work that would be helpful in improving efficiency, but the recommendations here are confined to work on the clearing of immediate bottlenecks, and also towards those basic studies that are considered in greatest need of attention. The problems can be described briefly under the headings Fundamental Research and Industrial and Economic Research.

A. Fundamental Research

1. Studies of the minerals in the deposit are required. More information on what metals are present, their form, distribution and relationship to the hydrocarbons is needed.
2. The study of the fundamental properties of the bitumens is very important and that information is needed for the development of the major divisions.

B. Industrial and Economic Research.

1. Mining and Proof of Deposit—

   The present position is that the only commercial areas proven are those determined by the drillings conducted by the Mines Branch. Although these serve for the present estimates more testing is required before large scale developments are undertaken.

   Mining represents 25% of the oil production costs, and the mining industry has no exact precedent for mining that type of material. To date mining has only been done to provide charging stock for little test plants, from relatively small benches in the river valley. With small scale mining operations of this material neither the problems nor the possibility of economies correspond to those that will be encountered with large scale operation when working the type of areas required.

   Mining investigations require to be carried out, and should include determination of—

   (a) The cheapest means of securing an adequate yardage of suitable material ready for loading with large scale equipment.

   (b) The possibility of attacking the deposit from below such as by the block caving method that has been suggested when using steam.

   (c) The possibilities of recovering the bitumen directly, with the least possible disturbance of the sand.

2. Processing Units Operating in the Area—

   The development of the Hot Water Process is well advanced. The aspects to which the survey would particularly draw attention as requiring study are—

   (a) Study of the inter-relationship, technically and economically of the water separation plant with the form of mining that will precede it, and the dehydration and distillation plant that will follow it.

(b) Studies directed to the simplification of the movements of the sand mass and liquid volumes within the plant with the object of minimizing plant size and utility requirements.

The application of the Fluidizing principle is very important to the bitumen development. Further information is required from—

(a) The further correlation of pilot plant results with commercial fluidizing plant experience.

(b) The securing of further data on the distribution and effects of fine minerals in the processing operation.

(c) Investigations into the possible combining of the fluidizing dehydration-distillation step with essential subsequent refining operations.

3. Sulphur Removal—

Mild hydrogenation is effective in converting the low grade high sulphur distillate to a first class product, but at the same time creates 50% of the total processing cost. Further study is required of the possible application of alternative sulphur reduction methods. Investigation is also required on some technical and economic aspects of the hydrogenation that are peculiar to this material.

RECOMMENDATIONS ON GENERAL POLICY

1. Policy Research and Development

It is recommended that provision be made for the co-ordination of all effective Research taking place on the Bituminous Sands. It is not considered essential at present that the co-ordination be placed on a particularly formal basis, as through leaving every opportunity for separate initiative the most effective progress may be made. It is considered essential, however, in view of the great overall importance of the results that the development of the bituminous sands could give, that—

(a) A general program ot what is considered to be the most necessary investigational work for the development of the resource should be drawn up as soon as possible.

(b) The program should be so established that the work will check and expand the present findings that have shown a practical sequence of economic and technical developments. At present there are existing facilities and technique in Government and Industry to expedite an appreciable part of the essential work.

2. The Bitumount Plant

It is recommended that the Bitumount Plant be maintained as a Field Testing Station. It has been shown that there is a considerable amount of field work to be done and it will all require power, steam, machine shops, housing, etc., such as is available at Bitumount. In addition the present plant will be required for providing stocks of bitumen and for checking possible processing economies arising from work elsewhere.

3. Government Policy on the Development of Bituminous Sand

The physical development, in the field particularly, of the bituminous sand differs in a number of ways from other resources as effecting the necessary controls, licensing and sale of the material. The mining study has emphasized that large unbroken areas with suitable surface terrain will be required for major projects. With the establishing now of the technical and economic aspects of efficient production it is recommended that the most effective Executive Policy for the resource should also be concurrently developed.

ALBERTA BITUMINOUS SANDS

CHAPTER I

General Description of Bituminous Sands

(The Raw Material for Evaluation)

The Alberta Bituminous Sands forcibly call attention to their presence by a series of outcrops along over 100 miles of the Athabasca River and its tributaries. The exposures vary from those of a few feet where small breaks in the overburden disclose the oil saturated sand to the cliffs of over 200 feet that appear at places along the river banks.

The underlying Devonian limestone can readily be seen in the vicinity of the town of McMurray. The upper part of the limestone formation is in hard massive bands and the top appears to be generally smooth and level.[1] The contact between the two formations and also the bedding and general type of structure in which the bituminous sands occur with their characteristic thickening and pinching out laterally of strata is very apparent.[2] The formation in general is dark brown or black in color. The rich beds appear fairly homogeneous, and have the characteristics of an unconsolidated sand saturated with a particularly viscous petroleum. The exposed bituminous sand aggregate tends to have a high angle of repose, strengthened by the oxidation and hardening of the bitumen content in the surface material. The geological position[1] of the bituminous sands is in the McMurray formation at the base of the lower Cretaceous.

(See pages 81 and 82 for all references)

EXTENT

The amount of country that is underlain by the bituminous sand formation is indefinite. Early surveys suggested some 1,500 square miles,[3] while later studies have mentioned areas up to 30,000 square miles[4] as possibly being the extent of the formation. With the increased knowledge acquired from the oil well drilling in the Northern part of the province, it is apparent that this type of material does exist over a large tract. The evidence from new drillings both in the way of cores and as samples of bitumen now make it very apparent, however, that in order to arrive at a total area for the bituminous sands it is necessary first to define what is accepted as being a significant part of the formation. In the drillings to the South and West bituminous sand has been found in various concentrations over a large section of country that indicates very widely spread boundaries of the formation. At the same time it is of interest to note that separated bitumen which appears to be identical to that found in the sands has been obtained from wells drilled into the upper Devonian limestone over one hundred miles to the West.

Comparisons of the amount of bitumen with the reserves of oil in normal oil fields[5] are only realistic if placed on the same basis which however, cannot be done with any precision at present. The percentage of the total bitumen that will be recovered may be much higher than the percentage of the total oil that is recovered under normal oil field development. From that portion of the bituminous sand which is mined, the bitumen is all potentially recoverable and the proximity of the formation to the surface may permit the development of extensive high recovery projects. At the same time only a percentage of the total bitumen can be considered as comparable in quality to normal crude oils.

The deficiency of the present data for the development of any definite estimate of the amount of bitumen even in the immediate vicinity of the Athabasca River was further shown by the Government drillings[6] which disclosed a barren formation West of the Mildred-Ruth Lake area and another North of the Muskeg River district. How limited such areas are is at present quite unknown.

The economic importance of defining the extent of the area at present is largely that of determining the amount of oil that is potentially recoverable with present methods, and associating with that determination some conception of the remaining oil as a form of insurance for later expansion.

The magnitude and tremendous importance of this resource however, are adequately proven without any determination of exact amounts. When the evidence from field work and in particular the very valuable drillings carried out by the Federal Government, is examined in conjunction with the clear proof[7,8] that has been established of the recoverability of the bitumen, it is seen that there is an amount of potentially useful oils in this deposit that places it in the category of one of the major oil resources.

ORIGIN

The origin of the bituminous sands has not been fully established. The formation is regarded as deltaic, and it is suggested that the sands originate from igneous rock formations to the East. Different theories are advanced as to the origin of the bitumen. One suggestion is that it originated in the cretaceous formation[9] while the theory is also advanced that it is from oil migrated into the formation from the underlying Devonian.[10] The present physical form in which the oil is found has been attributed to its being a residual product due to the escape of lighter components that occurred from the exposure of the formation. Another hypothesis has postulated that it originated as heavy oil in the Cretaceous. There is also the possibility that polymerization, possibly aided by natural catylists partly account for the present physical form of the oil.

When more is known about the source of the bitumen, and the reason for its being in its present form, it should materially aid both in the ease and economy of mining and recovery of the oils. Now, however, we are faced with the presence of this mammoth resource of a heavy viscous oil that in some cases amounts to more than 100 million barrels per square mile. It has saturated a strata that in places has only a very light covering, and over an immense tract of country is never more than a few hundred feet below the surface.

PROPERTIES OF PRINCIPAL COMPONENTS

Although there is great similarity between both the bitumen and the sand from different districts, detailed examinations show appreciable variations in the properties of both. Indeed the disparity in quality and the manner by which the two are combined contrast to such an extent that they create major differences in comparative values between districts. In general the variations in quality are so pronounced that comprehensive drilling and sampling is essential to establish the comparative merit of any particular location.

The mineral aggregate[11] is mainly quartz particles of 100 to 200 mesh size and smaller, but also particles of other minerals including mica, rutile, ilemite, tourmaline, zircon, pyrite and garnet occur. Clay interbedded with the bituminous sands is also a constituent.

The most pronounced physical properties of the bitumen are probably its gravity and viscosity. The specific gravities[12] vary from about 1.027 for the bitumen in the vicinity of McMurray to 1.005 in the Ells River district. There is a general tendency for the bitumen in the North to be lighter than that in the South. Bitumen with a specific gravity as low as 1.00 has been found in the North, but no appreciable quantity of this material has been ascertained. The importance of the gravity of the bitumen is readily appreciated in connection with any form of recovery or separation dependent on the use of water. The viscosity of the unaltered bitumen has been shown in general to be much greater in the Southern part of the area than in the North. Thus, at the Abasand quarry samples have shown the bitumen to have a viscosity at 50 degrees F. of 600,000 poises, whereas the viscosity of the bitumen in the Ells River and Bitumount district is only about 6,000 to 9,000 poises. The differences in the viscosity of the bitumen between district and district has a marked effect on the ease with which the bituminous sands can be excavated.

PHYSICAL RELATIONSHIP OF COMPONENTS

The physical relationship of the bitumen to the individual sand particles in the formation is very important, both in its effect on the ease of separating sand from the bitumen and also on the types of mining that can be applied. The subject, however, is one on which it is particularly difficult to secure significant basic technical values. This is because of both the variations in the water, bitumen and mineral matter in different localities, and also because of the problem of securing truly unaltered material for examination.

Variations in the quality of the components have been described previously, but further comment on the stability of the structure is desirable.

With reference to the problem of securing unaltered bituminous sand, it is found that hand specimens normally show the bitumen as surrounding the sand grains. Such samples, however, broken from a quarry or as a core from drillings, have experienced loosening or softening similar to that which is so evident in the material in a quarry face very quickly after its exposure. The loosening is at times partly due to change in temperature, but it is also due to a rearrangement of the sand particles.

When a rearrangement takes place of an unconsolidated sand in which the void spaces are filled with bitumen there is a tendency for this bitumen to spread and fully isolate more sand grains. Whatever the extent may be on exposure, to which additional isolation takes place of sand, as compared with the original arrangement, an extremely important condition is produced. The consequence of this phenomena of the bitumen tending to become a continuous phase through a mass of sand should be appreciated particularly as to its great potential effect on the possible methods of both mining and separation.

Studies[13] have been made of blocks of bituminous sand carefully removed from the formation during the winter when the temperature was low. It was believed that the samples had altered very little, and the following measurements were secured on them—

Specific Gravity	1.96
Porosity	39.2%
Percent Saturation—	
Oil	84.3%
Water	4.5%

The studies based on samples from farther North in the formation (the Bitumount quarry) led to the conclusion that the specific gravity there varied from 2.03 to 2.08. The total voids there varied between 33.0 and 35.5% of the volume of the undisturbed bituminous sands, and the total percent of saturation varied between 86.5 and 91.5%. The water saturation was between 3.5 and 14.5%. When the water saturation was high the oil saturation correspondingly decreased. From the analysis made at Bitumount 100% saturation, in that formation, would show 16.5% of bitumen.

The water naturally present in the bituminous sands is extremely important. Its quality, amount and distribution have been extensively studied. The position which it occupies in regard to the sand particles, apparently as a film on the quartz surface, is the key that permits the principle of simple water separation of bitumen and sand. The universal distribution of it in that way has permitted the developing of the present efficient water separation processes.

SECONDARY COMPONENTS

Sulphur

There are two other groups of components in the bituminous sands which although smaller in quantity are of major importance in their effect on development. One is the sulphur, which is present in such abnormally large amounts that it defines the type of plant and processes required for treating, and also because of the effect it has on the value of the products made. The other important component is the group of fine minerals and metals that occurs in the bituminous sands aggregate. The immediate importance of these minerals and metals is in their effect on the subsequent refinery plant and processes.

The amount of sulphur in the raw bitumen varies appreciably throughout the area but in general may be considered as being between 4.5 and 5.5% by weight of the dry bitumen. A few commercial crude oils have between 2 and 3% sulphur, but the great bulk of even sour crudes have less than 1.75% sulphur. The sulphur in the bitumen is in chemical combination with it. When the bitumen is distilled the sulphur is found to be fairly uniformly distributed throughout the whole range of distillates.[14] A small percentage of the lowest boiling distillates have a sulphur content in the order of 1.75% while in the bulk of the lighter ends the sulphur content varies from 2.5 to 3.5%. Thus distillation and fractionation alone do not permit the segregation of any particularly high or low sulphur-carrying distillate. When referring to the segregation of sulphur, however, it is particularly interesting to mention that the study in progress at present at the Mines Branch, Ottawa,[15] of the unaltered bitu-

men when using a chromatographic analytical approach, shows the presence of an appreciable amount of cyclic paraffins which are virtually sulphur free and are associated with aromatics high in sulphur.

Oil refinery technique now permits the economic processing of high sulphur crudes such as those that occur in parts of West Texas, California, Wyoming and The Middle East. The special plant required for the handling of high sulphur oils has to some extent increased the operating costs, but it is effective and the plant corrosion from such crudes is now reasonably under control.

The effect of a high sulphur content in the charging stock on the quality of products, however, is of major importance. The extensive use of tetraethyl lead in the manufacture of gasoline to improve its anti-knock properties, is one reason that compels the sulphur content to receive special consideration. Although the various sulphur compounds differ in the amount they decrease the responsiveness of gasoline to tetraethyl lead, they all have a decidedy depressing effect. Sulphur contents are kept to about 0.05% or lower to ensure avoiding a serious loss in value. In some lubricating oils there is a tendency at present to increase the sulphur tolerance and it has also been increased appreciably in some heavy fuel oils. Fuels in general, however, which have high sulphur contents are liable to be discounted in price in comparison with those with a low sulphur content.

In view of the exceptionally high sulphur content in this bitumen and the effect on the value of the products, the refining studies of this survey have provided for removing sulphur to a sufficient extent to allow the products made to be evaluated on a normal oil market. The survey has also included a study and estimate of both the cost of recovering the sulphur and of its value in Western Canada.

Metals and Heavy Minerals

The significance of the colloidal minerals and metals in the bitumen, is a more unknown subject at present than is the case with sulphur. The presence and removal of traces of metals such as vanadium from some crudes has been dealt with in the oil industry for some time. The most detrimental effects from their presence is the danger of poisoning the catalyst used in refining and creating excessive treating losses. Distillates from the bitumen, have been produced showing a metal content in the order of ten times those from other heavy crudes.

METALS BY QUALITATIVE EMISSION ANALYSIS
(Parts Per Million)

Distillates (after settling) produced by Fluidized Solids Distillation

Samples from	BITUMOUNT		ABASAND	
Extreme Values	Lower	Upper	Lower	Upper
METALS—				
Iron	1.0	4.0	3.0	14.0
Manganese	0.4	1.5	0.05	0.2
Nickel	1.0	6.0	3.0	12.0
Vanadium	7.0	30.0	10.0	40.0
Lead	0.2	1.0	0.2	0.8
Copper	0.3	1.5	0.5	3.0
Zinc	0.2	1.0	0.5	2.0
Tin	0.05	0.2	0.5	2.0
Aluminum	7.0	30.0	1.0	6.0
Magnesium	10.0	40.0	0.7	3.0
Calcium	7.0	30.0	2.0	8.0

The foregoing tabulation illustrates the substantial amounts of the metals that have been found in distillates during this survey. The quantities in the distillates are to an appreciable extent dependent on the methods by which the oil has been prepared. Some samples have been produced in the investigations showing many times the amounts indicated here, but this average distillation when processing the complete bituminous sands serves to indicate the presence and something of the importance of the metals associated with the bitumen.[16]

It has been suggested that the source of some of the metals, for example vanadium, is from the same neighboring igneous rock that was probably the source of the sand. The possibility that such metals however, are from the original metal salts that were formed during the life of the oil source material, seems to be much more likely and would account for their present form of distribution.

The presence of such metals elsewhere in very appreciable quantities in oil formations has been chronicled and shows extremely wide variations.[17] M. Blumer[18] for example has found up to

0.35% of vanadium in the total ash from oil shales. Higher percentages have been found in manjak or grahamite[20] while the commercial recovery of metals has been developed including uranium from Estonian oil shales in Russia. The work of the Bureau of Mines on Colorado Shales[19] has indicated that the most of the metallic constituents in their oil shale are non-volatile under normal retorting conditions.

It may be that the high percentages of metals which are found in the present distillates made from bitumen are due to an appreciable extent to the close physical proximity and the ease of movement between any mineral body in the oil subjected to distillation and the distillate. The limited opportunities that this oil distillate has between its production and collection for any settling or filtering in comparison with the opportunity for separation experienced by normal crudes of similar gravity is very apparent.

Attention will be drawn to heavy minerals appearing in separating methods using water, and their appearance as finely divided metals in distillates from bitumen has been noted. The possibility might be considered as to whether the heavy minerals have any commercial value in themselves. The work to date is not adequate to answer fully this question. It is of interest, however, to note that although the metal content in the sand could be below the amount ordinarily required for economic recovery, that in this case a much lower percentage of the heavy minerals would justify recovery because of the proportion of the mining and treating costs that are borne by the bitumen operation. At present, however, the knowledge of the amounts, quality and distribution of the metals in the sand is too limited to make a close estimate of their values, or the magnitude of any credit which they might provide as a by-product to bitumen recovery operations.

OTHER BITUMINOUS FORMATIONS

The bituminous sands of Alberta, although by far the most extensive, are by no means the only bituminous sand deposits. Bituminous sands, sandstones and limestones occur in many countries throughout the world. These materials have been mined and used quite extensively in Europe for paving work and making bituminous mastics, for flooring and other applications.

In the United States asphalt rock in different forms occurs in at least ten States.

The developments, mainly local, that have been directed to the utilization of this material have tended to consider its application principally for road and mastic purposes. In California there are a number of bituminous sandstone occurrences that have been mapped by the Geological Survey. The Bureau of Mines undertook a study of the separation of oil from bituminous sandstones by the hot water washing process. The laboratory results when using California sandstones have shown some features quite different from corresponding results with Alberta material. The presence of a considerable quantity of soluble salts, mainly iron and calcium sulphates, has been a complicating factor in the case of the California material. The presence of such salts in Alberta bituminous sands has been observed in one abnormal location. Normally they are absent. In general the Alberta deposit, from the point of view of ease of removing and recovering the oil or bitumen as well as the magnitude of the deposit, is particularly attractive in comparison with other deposits.

SUMMARY OF CHAPTER I

1. **The Extent** as defined by outcrops and drillings proves a vast deposit. There appears to be a few square miles that each contain 200,000,000 bbls of bitumen and possibly an appreciable number that contain 100,000,000 bbls. The evidence is inadequate to appraise the total bitumen because of the absence of information as to the formation boundary and also as to the extent of the barren tracts within the formation.
2. **The Theories** of origin and quality are outlined. Work on the fundamental properties of bitumen and the presence of metals could assist clarification and development.
3. **The Mineral** Aggregate is mainly quartz particles of 100 to 200 mesh size and smaller. The remaining minerals, usually less than 5% apart from the clay, are much more difficult to eliminate from both the bitumen and the oils than is the case with quartz and they require further study. Some of the rare metals may justify recovery.

4. **The Bitumen** varies in specific gravity from 1.005 in the north to 1.027 in the south and similarly in viscosity from 6,000 poises at 50 degrees F. in the North to 100 times that in the south.
5. **The Secondary Component, Sulphur**, is very important, averaging 5%. It is distributed throughout the distillation range although there are cyclo-paraffins present that are sulphur free. The oxygen and nitrogen correspond to the amounts in crude oils.
6. **Other Bituminous Sand Formations** are small in comparison with Alberta's and in general the bitumen is not so readily recovered. The raw material from some of the others is much more suitable for direct use.

CHAPTER II

Process and Work Directed to the Developing and Evaluating of the Bituminous Sands

(The Tools for Evaluation)

There have been approaches to the development of the bituminous sands for many years. Those have varied all the way from thorough technical studies and developments of some specific aspects of the work to the approaches that were based on little more than the impressions of early Northern travellers, on finding the gigantic deposit on each side of their watercourse to the North.

This Chapter records the processes and data particularly applicable as tools in the evaluation of the resource.

A study has been made of the mining problems that will be encountered in large scale operations. The costs of removing and disposing of overburden and of mining bituminous sands and removing the tailings have been estimated.

A brief description is given of the treating processes that have been specially developed for the handling of this material, (such as initial methods of recovering bitumen or oil from the sand) noting in particular the most recent progress made.

Where proven commercial processes have been adopted from the oil industry to carry out some phase of the operation such as Propane Extraction of the bitumen or Catalytic Cracking of the gas oil, only the application to these materials and the results of the tests are recorded.

MINING of THE BITUMINOUS SANDS OF NORTHERN ALBERTA

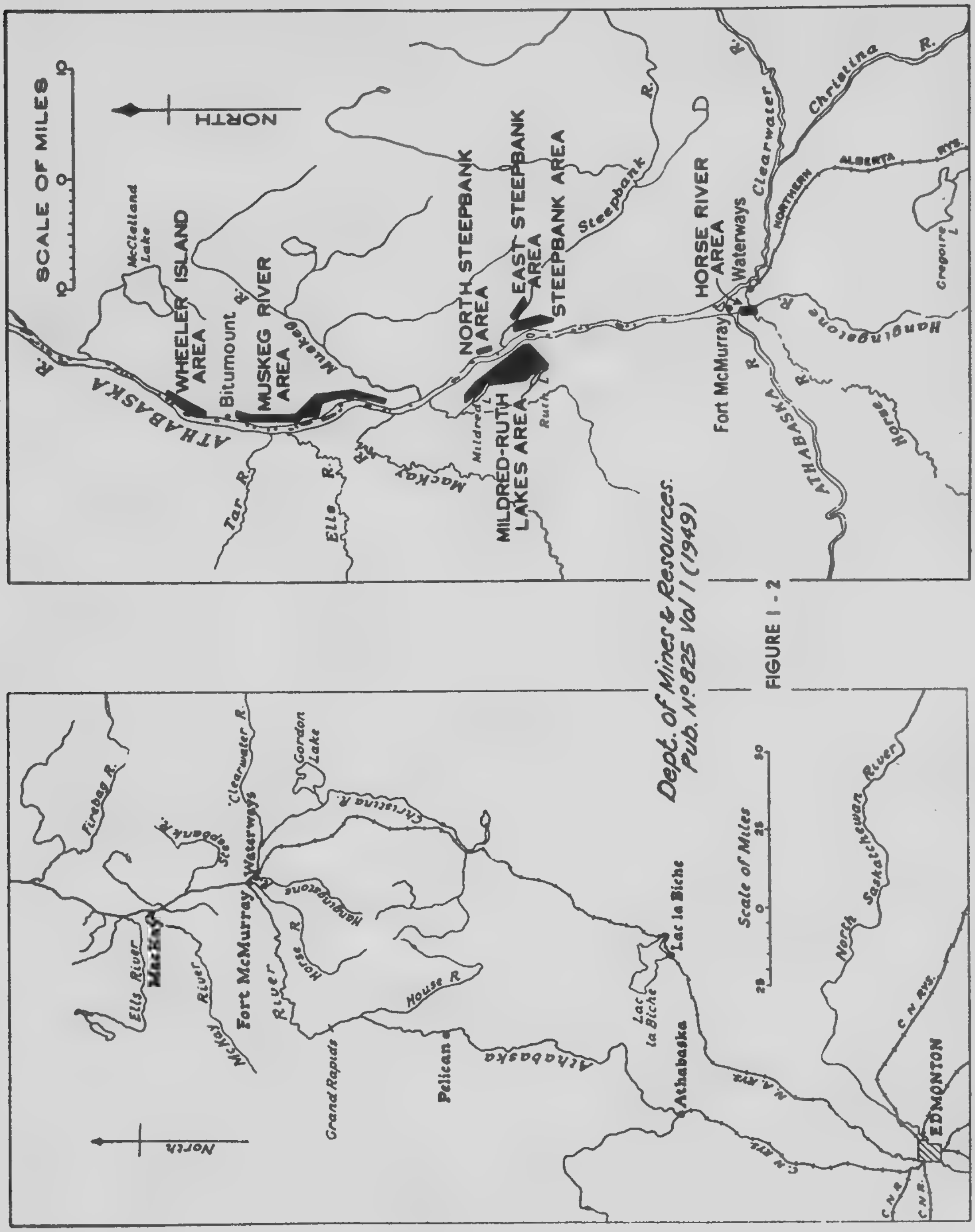
The mining of bituminous sand for subsequent bitumen recovery is essentially a large scale development. A project requiring 20,000 barrels of oil per day requires approximately the same number of cubic yards of rich sands delivered to the separation plant. This results in the handling of over 6 acres of a 60 foot bench per month.

In order for mining costs to be determined on such an operation it is necessary first to establish a site where there is a suitable acreage of raw material permitting continuous production over the required number of years.

The proving of bituminous sand strata back from the valley of the Athabasca River* can only be done by drilling. With the object of exploring the nature of the bituminous sand formation and determining actual volumes that could be available for large scale operations, the Department of Mines and Resources at Ottawa initiated a drilling program** in the Spring of 1943[6].

The work was carried out from June, 1943 to January, 1947, under the supervision of the Mining & Geological Branch. There were 291 holes drilled representing a total footage drilled of 53,918 feet.

* Maps I and 2.
**Map No. 3.

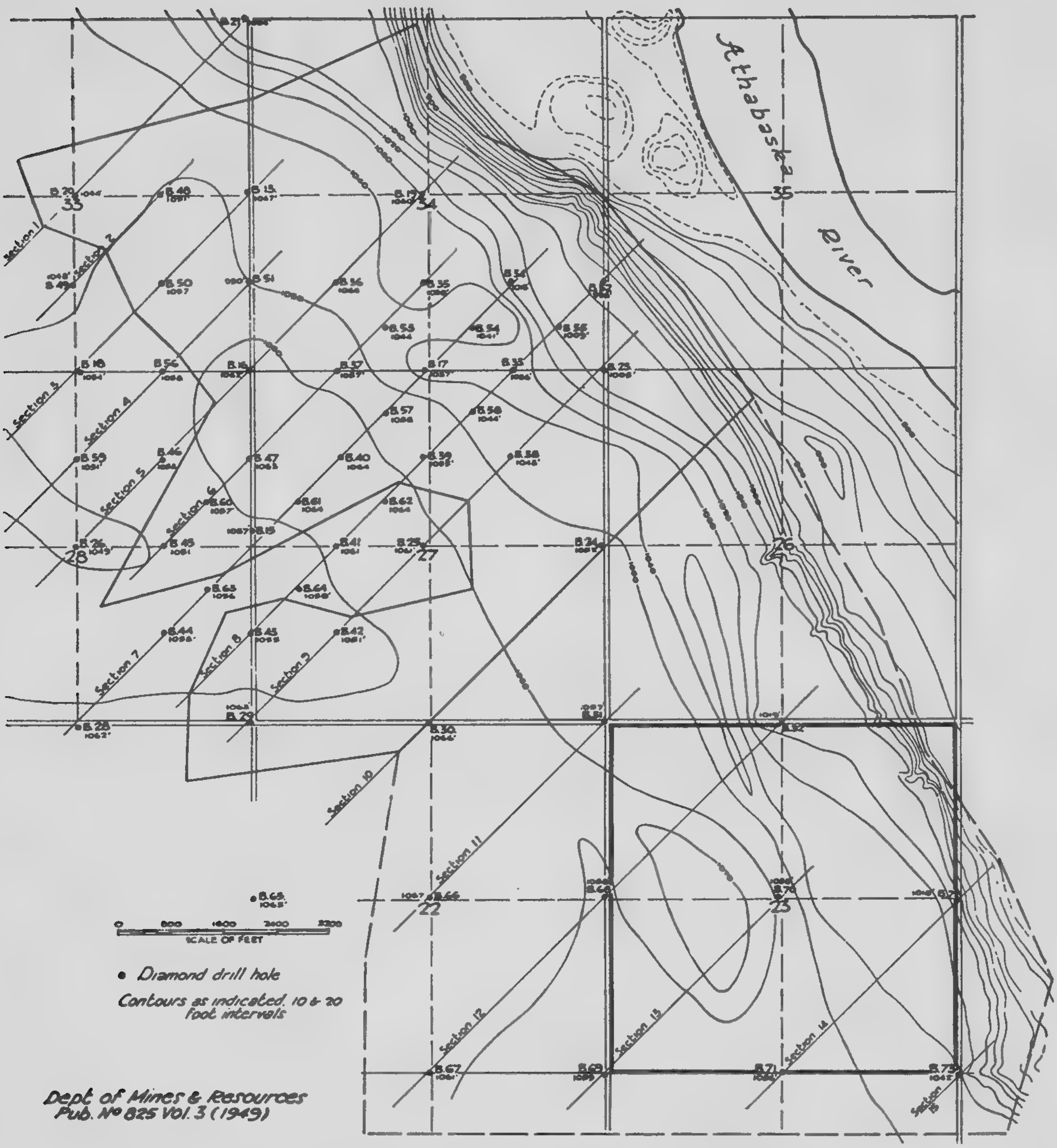


Dept. of Mines & Resources. Pub. No. 825 Vol I (1949)

FIGURE I - 2

KEY MAP SHOWING RELATION OF FORT McMURRAY TO EDMONTON, ALBERTA.

KEY MAP SHOWING AREAS EXPLORED BY DRILLING SINCE 1943.



FROM THE GEOLOGICAL SURVEY OF CANADA'S
MAP OF THE
BITUMINOUS SANDS EXPLORATORY DRILLING
MILDRED-RUTH LAKES AREA
TOWNSHIP 92, RANGE 10, WEST OF 4TH. MERIDIAN
NORTHERN ALBERTA

FIGURE 3

Diamond Drilling

The drilling was efficiently carried out. A method of core-drilling in the bituminous sand strata was developed using diamond drills and gel-mud drilling fluid.

Holes averaged 185 feet in depth with the deepest hole drilled to over 300 feet. Casing was unnecessary except through overburden, and core recoveries were usually from 93 to 98 percent. A dry compact core was obtained which could be split for sampling and assaying.

The logging and splitting of the core was done by the engineers of the Mines and Geology Branch. One half of the core was shipped to Ottawa and the assays for bitumen content, screen analysis etc. were made by the Division of Fuels, Bureau of Mines.

Selection of Site for Mining and Bitumen Evaluation Purposes

The only districts that have been sufficiently tested in the bituminous sand area for large scale mining operations are those which were studied in the Federal Government's drilling program. For the purposes of this survey proof was required of suitable bituminous sands that could be secured adjacent to a plant in quantities of at least 20,000 cu. yards. per day for a period of 15 to 20 years. For this purpose Section 23 in Township 92, Range 10, West of the 4th Meridian was selected as being the most convenient or economical area for a large scale project. It is, however, an area that is reasonably well proven now by drillings as to volume of raw material and as shown by the analysis of core samples. It is thus considered to be a suitable site for the preparation of production costs.

Section 23, Township 92, Range 10 West

SUMMARY OF DRILLING *

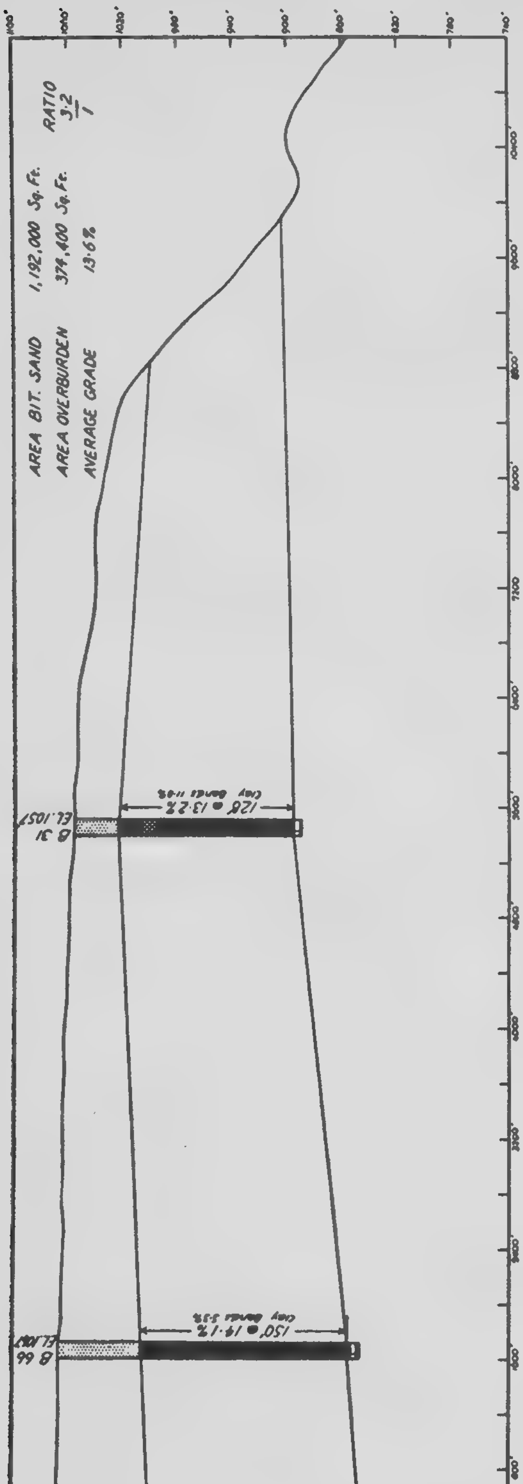
No. of Holes	Bitumen %	Clay %	Feet Bituminous Sands	Millions tons Bituminous Sands	Ratio Bit. Sand to Overburden	Overburden Feet
6	14.17	3.29	127.2	227	3.93	32.3

OPEN PIT MINING

The relatively low overburden in section 23 and high bitumen content of the underlying sands, at once suggests the possibility of stripping off the overburden and mining the bituminous sands with modern open-pit equipment.

With the object of initiating the study of open pit mining methods to conditions existing in the oil sand deposits, the engineers of the Fred Mannix Company of Calgary have made a comprehensive investigation of the costs of removing the overburden and excavating bituminous sands for delivery to a treating plant. Their experience in strip coal mining in Alberta and with construction generally throughout Canada adds greatly to the value of their observations and estimates. They have made a study of open pit mining and tailings disposal commencing on level terrain, and also a study directed to mining such as that of Section 23 mentioned above. Here the overburden consists mainly of sand, gravel, clay, boulders and glacial drift with some sandstone and shale.

* Diagrams 4 and 5



MILDRED-RUTH LAKES AREA SECTION 11

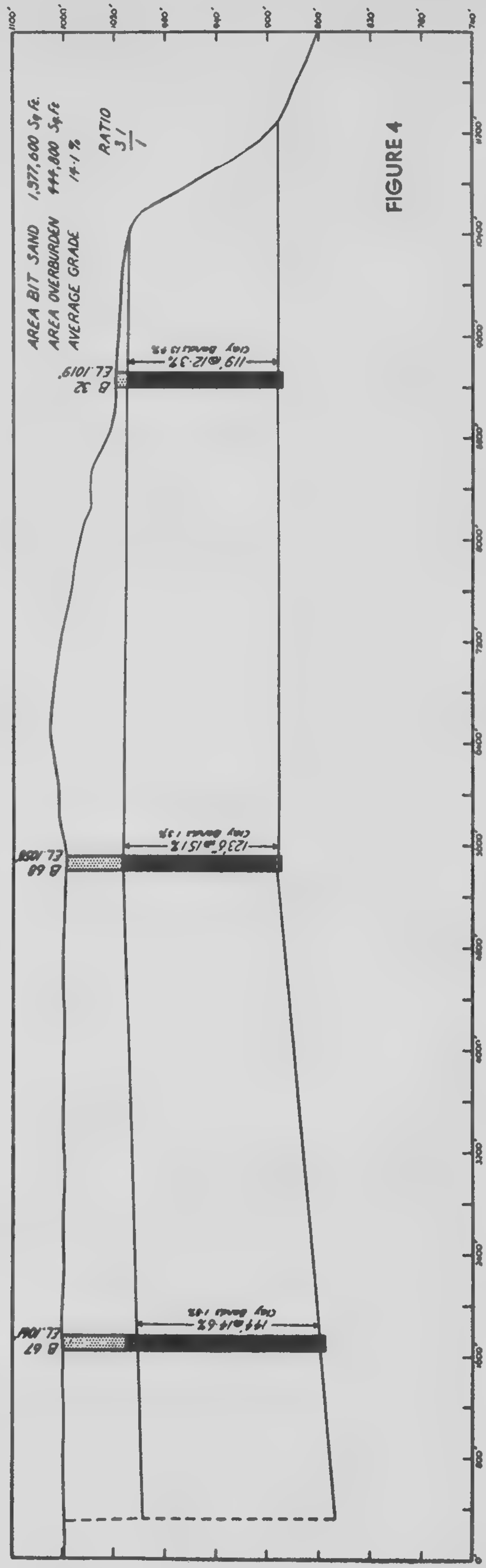
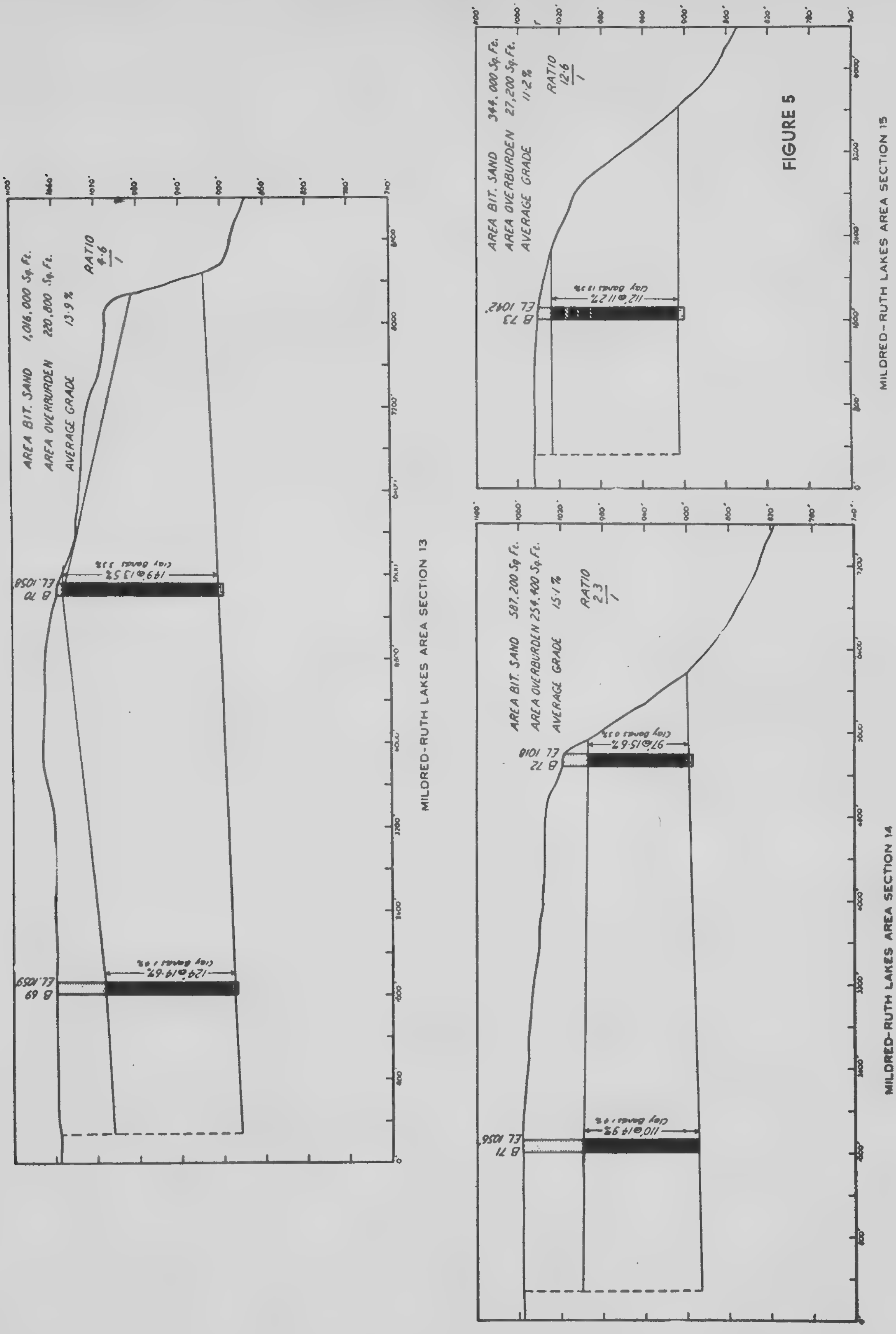


FIGURE 4

MILDRED-RUTH LAKES AREA SECTION 12



MILDRED-RUTH LAKES AREA SECTION 13

MILDRED-RUTH LAKES AREA SECTION 14

MILDRED-RUTH LAKES AREA SECTION 15

FIGURE 5

Removal of Overburden

(1) Using 8, D-8—12 cu. yd. scrapers and 2, D-8 pushdozers, Mannix have estimated that by working in the four to five warmest months of the year the overburden could be excavated and moved an average of 800 feet for a total cost of $0.19 per cu. yd. equivalent to $0.05 per cu. yd. of oil sand where the ratio of sands to overburden was 3.7 to 1.

Over the whole of the Mildred-Ruth Lakes area drilled, the overburden was much deeper, the ratio of sands to overburden being 2.6 to 1. It seems but natural therefore, to consider the use of much larger equipment for this purpose, equipment which might later prove useful in the mining of the bituminous sand itself.

(2) With the aid of walking dragline excavators, using 25 and 20 cu. yd. buckets respectively, two of the strip coal mine operators in Indiana have obtained the following costs in removing 60 to 100 feet of overburden.

(a) Using a walking dragline with a 215 ft. boom and a 25 cu. yd. bucket 6,969,200 cu. yds. were removed in one year from a bank averaging 65 feet in height and including 12 to 15 feet of dense compact sandstone.

	Cost Per Cu. Yd.
Excavating Only	$0.0305
Drilling and Blasting	.0605
TOTAL	$0.091

(b) A large walking dragline equipped with a 20 cu. yd. bucket moved an average of 1,580,000 cu. yds. per month. In this case the banks were 65 to 100 feet high and contained beds of Indiana limestone which have to be drilled and blasted. The total cost was $0.0875 per cu. yd.

In excavating the overburden at the strip coal mines in Indiana the greatest variable is the drilling and blasting cost of the beds of sandstone and limestone that are frequently encountered. In the case of (b) cited above a 5 inch wagon drill is used for drilling the beds of limestone. Liquid oxygen made on the property is used for blasting.

Disposal of Overburden

In the initial operations on the bituminous sands it would be advisable if possible to dispose of the overburden on a site where it would not have to be moved in later operations.

The map* of the exploratory drilling in the Mildred-Ruth Lakes area shows that the shelf between the bituminous sand escarpment and the river is amply wide for such purpose. After the oil sands have been mined to the underlying limestone and a sufficient area exposed, overburden can be dumped in the space formerly occupied by the bituminous sands.

The haulage distance in the initial operation will very likely not exceed 1/4 to 1/2 mile. In later operations, part of the overburden might be cast directly into the space from which the oil sands had been removed and the balance would not have to be hauled more than 1/8 to 1/4 mile.

With 30 ton haulage equipment now in common use, cost of hauling should not exceed $0.12 per cu. yd. of overburden. In the Mildred-Ruth Lakes area where the ratio of bituminous sand to overburden is 2.6 to 1, the disposal cost of the overburden should not exceed $0.05 per cu. yd. of bituminous sand when carried out on this size and type operation.

Drilling and Blasting Bituminous Sands

During the Summer months at Bitumount a 3/4 yard shovel could dig as much as 20 inches off the face of the bituminous sands if the face had been exposed to the atmosphere for about 24 hours. During the same months at Abasand, however, it was found necessary to loosen the banks by blasting before a 1-1/4 yard shovel could be used to advantage.

* Map No. 3.

For mining large tonnages and for carrying on Winter operations it would appear essential to loosen the banks by blasting before attempting to load.

In the open pit layout* with 50 to 60 foot benches, blast holes drilled 30 feet apart and 50 feet back from the face would probably be adequate to loosen the mass sufficiently to permit easy and rapid loading with either large electric shovels or walking dragline excavators.

In 1942 drilling tests were made in the Horse River area near McMurray under the supervision of the Consolidated Mining and Smelting Company. Here holes drilled 12 feet apart and 12 feet back from the face and to a depth of 20 feet, loosened the bituminous sands in front of the blast and large cracks were observed as much as 10 feet behind the blast. In these tests the holes for blasting were made with steam jets. It might be that large size diamond drill holes, further enlarged at the bottom to take a greater powder charge would be satisfactory. Experimenting might show that rotary or churn drills with the use of gel-mud drilling fluid could drill even 9 inch or 12 inch blast holes satisfactorily.

For handling large tonnages in the Mildred-Ruth Lakes area it is doubtful if drilling and blasting costs would exceed $0.12 a cu. yd. and as experience was gained in actual operations the cost might very likely be reduced materially below that amount.

Excavating Bituminous Sands

Nothing in the preliminary operations has indicated that the largest size shovels or walking dragline excavators would not be entirely satisfactory for the handling of the bituminous sands once the solid mass has been disturbed. Material that can be handled by a 1-1/4 yard shovel can be handled more cheaply by a 6 to 8 yard shovel, while a 13 to 25 yard walking dragline could quite possibly handle the same material to still greater advantage. At the strip coal mines in Indiana it has been found that the advantages of draglines far outweigh their disadvantages and that their inability to crowd the material tends to disappear with the larger more powerful draglines.

Using this larger equipment it is not expected that the excavating cost alone would exceed $0.06 per cu. yd.

Haulage

With bottom dump, diesel operated trucks of at least 30 tons capacity and an average haulage distance of 700 feet, haulage cost has been estimated at $0.11 per cu. yd. For Winter operations in the Mesabi Range mining dump trucks are now so equipped that the exhaust from the engine is used in heating the bottom of the truck, greatly facilitating dumping.

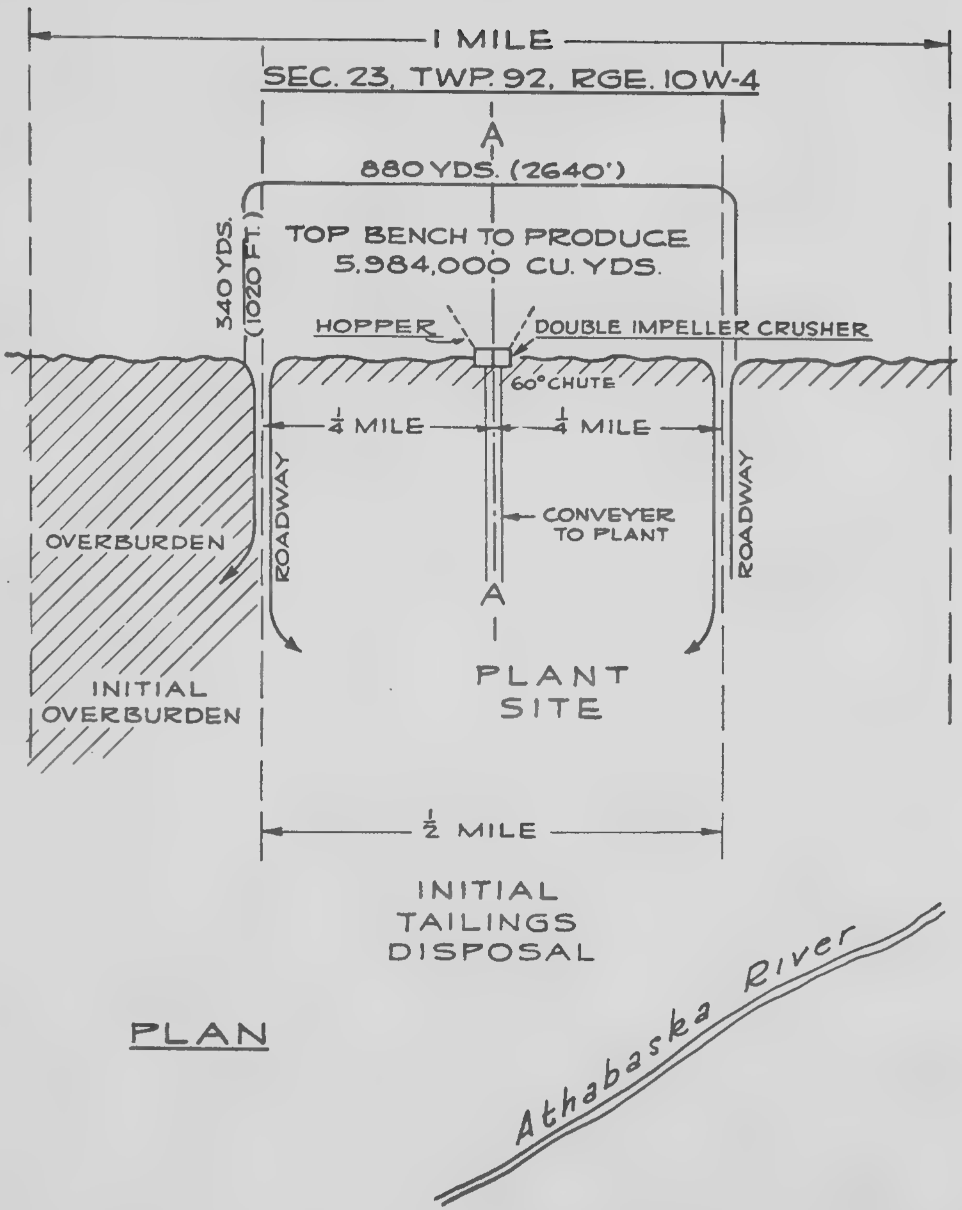
As the bituminous sand is known in places to contain some shale, gravel and boulders, the material as excavated, should be dumped over a grizzly with openings of a suitable size for screening out all of the large pieces of foreign material. The grizzly would also assist in breaking up any large lumps of the oil-sand which remained after blasting and shovelling.

The material passing the grizzly would fall into a hopper thence through a feeder and suitable crusher to a 36 inch conveyor leading to the treatment plant. With a site within 1,000 or 1,200 feet, total cost of crushing and conveying should not exceed $0.085 per cu. yd. With experience on the cost of crushing the Mildred-Ruth bituminous sands and the disposal of the foreign material, it may be found possible to reduce appreciably this allowance.

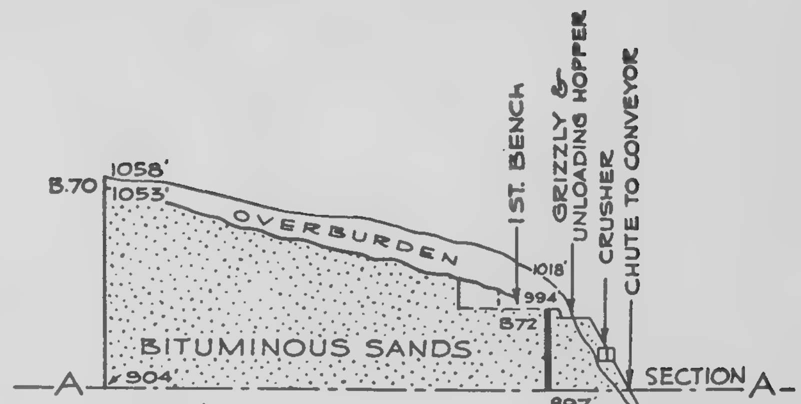
The total cost of $0.550 per cu. yd. by open cast mining is itemized in the summary in Chapter III with the total evaluation of the bitumen.

* Diagram No. 6.

FIGURE 6



PLAN



SECTION

PRELIMINARY OPEN PIT LAYOUT

1ST. BENCH - 0 TO 60 FT. HIGH
2640 FT. (1/2 MILE) WIDE

EXPERIMENTAL STEAM METHOD
FOR
UNDERGROUND MINING OF BITUMINOUS
SANDS

It has been pointed out in several instances in earlier reports on the behavior of the oil-sands that when exposed to temperatures about 45 degrees F. at Bitumount, and around 90 degrees F. at Abasand, the viscosity of the oil in the sands changes and the exposed face is softer and easier to dig.

The above characteristic of the sands has suggested to the engineers of the Fred Mannix Company that if steam was exhausted into a closed chamber under the bottom of a deposit of bituminous sand and the deposit was exposed to a slow continuous heat, the sand would begin to loosen and drop. If the loosened sand was drawn off through raises onto a belt conveyor, a larger chamber would be exposed to the heat and if sufficient drawpoints were provided a condition would develop somewhat similar to that encountered in block caving in large underground mining operations. This would permit continuous operations, without removing overburden and with a minimum size mining plant. Areas in which the overburden was very deep could be treated in this manner just as easily as areas in which the overburden was shallow.

Should experiments indicate that the total amount of heat required by such a method might be feasible the following underground experiment on a working scale has been proposed.[21]

Outline

A 10 x 10 foot haulageway, 1,000 feet long to be driven in the underlying limestone.* Cross-cuts to be driven from the haulageway at intervals of 100 feet extending 250 feet on either side of the main adit.

Raises to be driven at intervals of 100 feet from the back of all the openings, through the limestone until the bottom of the bituminous sand was exposed. Raises to be equipped with jacketed metal liners through which steam could be introduced and allowed to escape and come in contact with the overlying bituminous sand. The liners of the raises would extend low enough so as to discharge the oil-sand as it dropped directly onto a belt conveyor feeding the treatment plant.

It is expected that the space above each raise would gradually enlarge until it would break through to the space around the adjoining raises as is the case in block caving. The accompanying sketch shows in a general way what it is expected would happen.

From the data now available it has been estimated that, with a suitable steam plant, a volume of 18,000,000 cu. yds. of oil sand could be delivered to a treatment plant for a total of $6,878,206.

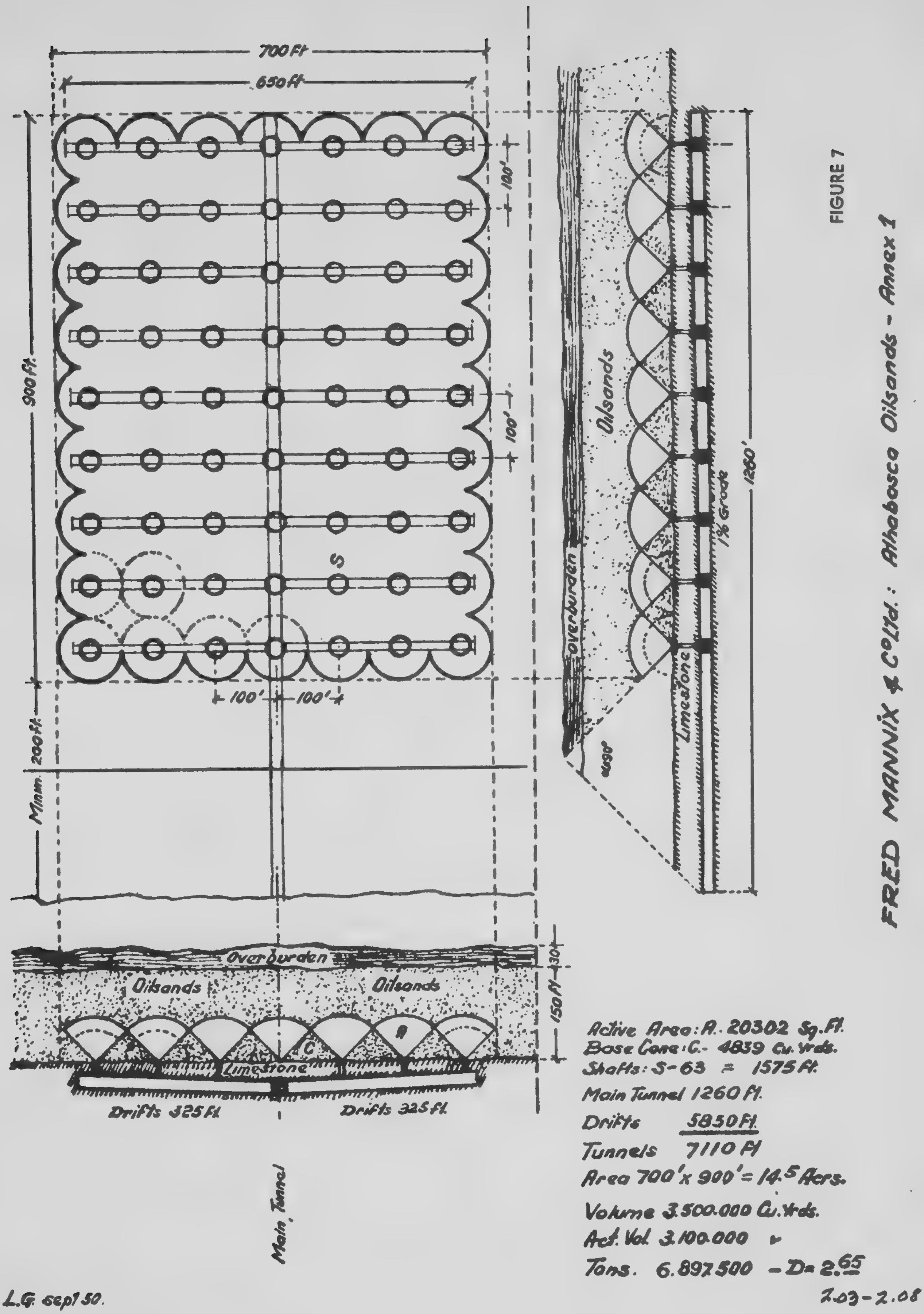
	Per Cent	Per Cu. Yd.	Total
Installation of Plant	36.12	0.138	$2,484,000.
Operating Cost	32.72	.125	2,250,000.
General Expense	31.16	.119	2,144,000.
	100.00	$0.382	$6,878,206

Ventilation with a blower was considered in the above but it might be advisable to provide in addition a ventilating raise from the end of the haulageway through to the surface. If equipped with a ladderway it would provide a second exit to the surface in case of an accident and at the same time improve the ventilation.

Provision would have to be made for removable liners in the raises and for some means of regulating the feed to the conveyor.

Spacing of the raises, or draw points, is another item which should receive careful

Diagram No. 7.



700 Ft
650 ft
900 Ft.
100'
100'
S
100'
100'
200 Ft.
Minm.
Overburden
Oilsands
Limestone
1% Grade
1260'
Overburden
Oilsands
Oilsands
A
C
Limestone
30
150 Ft
Drifts 325 Ft.
Drifts 325 Ft.
Main Tunnel
Active Area: A. 20302 Sq.Ft.
Base Cone: C.- 4839 Cu.Yrds.
Shafts: S-63 = 1575 Ft.
Main Tunnel 1260 Ft.
Drifts 5850 Ft.
Tunnels 7110 Ft
Area 700' x 900' = 14.5 Acrs.
Volume 3.500.000 Cu.Yrds.
Act. Vol. 3.100.000 "
Tons. 6.897.500 - D= 2.65
L.G. sept 50.
2.03 - 2.08
FRED MANNIX & Co Ltd.: Athabasca Oilsands - Annex 1

FIGURE 7

HOT WATER SEPARATION

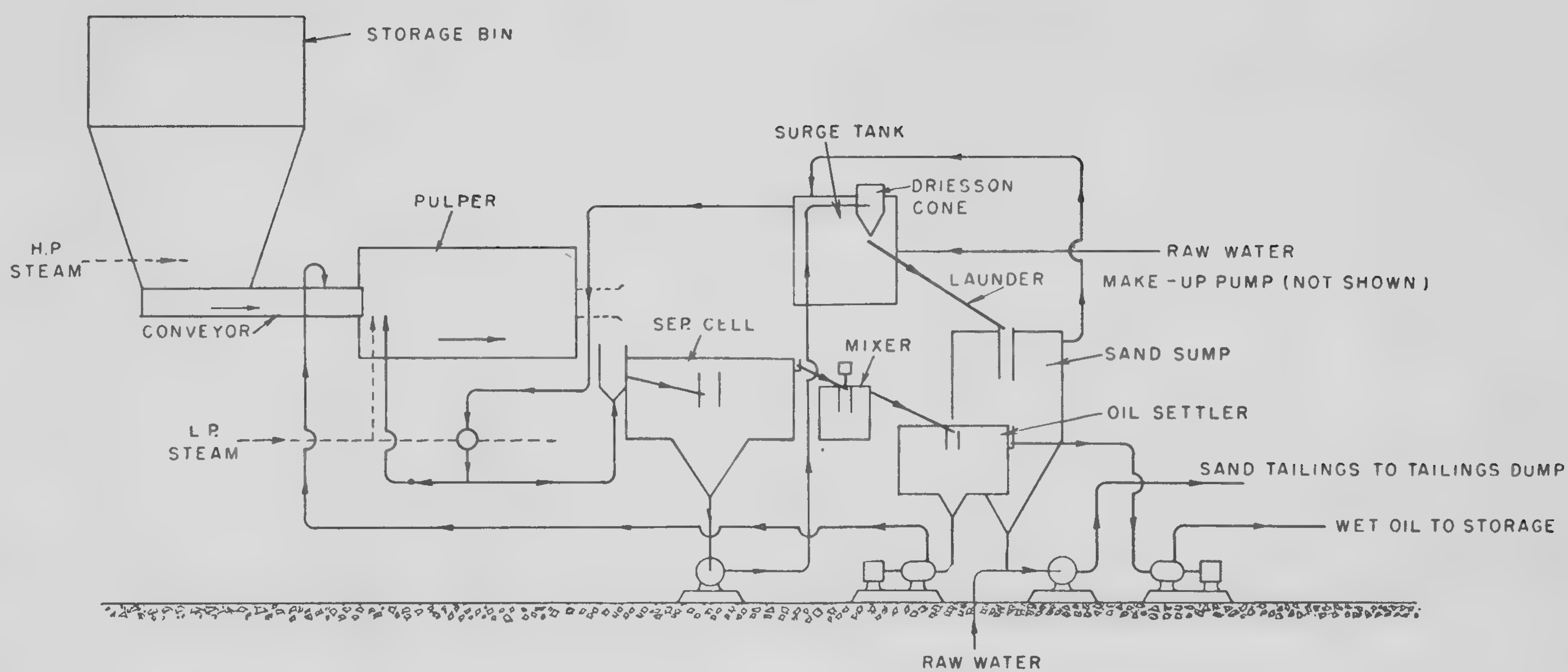


Figure 8

ELEVATION OF A SEPARATION PLANT UNIT

consideration. In block caving practice, raises would generally be spaced closer together but the best spacing for extracting the bituminous sands could only be determined in actual practise.

The percentage of the total sands that could be recovered by this method is of course uncertain, but in view of the vast extent of the deposit it is not of major importance as long as costs are kept at a minimum. The possibility of carryingon all year operations, independently of the weather or overburden is of great importance.

RECOVERY OF BITUMEN FROM SANDS IN PLACE

The steam method referred to above would obviate the removal of the overburden covering the bituminous sands but it would still entail the removal of the enormous tonnage of sand containing the oil. Any method which could be developed for extracting the oil, leaving both the overburden and sand in place might prove to be of the greatest economic value.

A somewhat analagous case is that of a large copper property in New Mexico. Dumps containing millions of tons of overburden, removed in order to expose the underlying sulphide copper ores, were known to contain a very small percentage of oxidized copper. Tests showed that by leaching, with a dilute sulphuric acid solution, a large part of this copper could be dissolved and then recovered in a marketable form. After the plan was put in operation it developed that the cheapest copper produced at the mine was that obtained from leaching the dumps containing the oxidized copper.

Regardless of what initial plan for large scale operations is adopted for treating the bituminous sands, the future would still hold out the great hope that a scheme might be developed for the recovery of the oil without ever disturbing either the overburden or sand except possibly by drilling.

HOT WATER SEPARATION

Theory of Separation

The separation of the Alberta bitumen from sand with the aid of hot water has been extensively studied.

The principles by which bitumen can be efficiently separated from quartz sand with the use of hot water are thoroughly described in the publications of the Research Council of Alberta.[22, 23]

The Council has maintained a continuous research program on different phases of the bituminous sand problem for many years. It was considered from the inception that the basic problem was to find a means ot recovering the bitumen while exercising as little work as possible on the sand. It was further considered that the properties of the bitumen and of the bitumen-sand mass were such that they presented an entirely different problem in recovery to that encountered in normal crude oil production. The oil industry could, therefore, not be expected to produce a recovery process adaptable to the bitumen as a natural part of the industries' technical growth. In view of this, work was directed to the finding of an economical means of recovering the bitumen from the sand, in the hope that if successful, regular oil refinery processes would be available to handle the separated material.

Their successful research has at the same time had to solve a great range of associated problems such as those resulting from all the different combinations of the different bitumens found with the different sands and fine mineral aggregates. Further after the clarification of the basic principles of the separation process it was necessary to develop a possible industrial application which was successfully undertaken by the Oil Sands Project Committee.[8]

The research has shown that when an intimate mixture of bituminous sand and water is heated the oil separates from the sand and disperses into small flecks of variable size that lie among the sand grains. The oil in this pulp can be collected by flooding it with an excess of hot water. The larger flecks become readily associated with air and water vapor and float to the surface of the water where they form a fairly stable froth that can be conveniently removed. It has been found that the

clayey material in the bituminous sand is closely associated with the oil dispersion and its possible collection.[24] The presence of a certain amount of fine materials has been shown to aid the separation. At the same time the presence of clay appears to result in a part of the bitumen being in small flecks which fail to float to the surface when introduced to the large volume of water. The greater amount of clay the greater this tendency for a dispersion of suspended material in the water with the bitumen that does not rise as a froth.

A certain amount of air assists in the floatation of the bitumen but it must be strictly limited. If there is a pronounced aeration it is found that there is a strong tendency for a great deal of sand to be carried to the surface with the oil air bubbles. With suitable operating conditions a bitumen froth can be produced that does not carry more than 5% of mineral matter and it usually has around 30% of water. The operation can be so directed that the primary froth accounts for about 90% of the total bitumen and it has been shown that an additional 5% can be efficiently recovered by the further treatment of the material in suspension. Thus it is possible to attain a total yield of 95%.

The quartz sand which has fallen to the bottom in the separating zone can readily be removed by mechanical means. The sand is clean, white in appearance, carrying only a trace of oil and when agitated with about an equal volume of water can be readily pumped.

When the bitumen is removed from the mineral aggregate with the assistance of water it is found that there is a difference in the ease of separating bitumen from quartz to that of separating bitumen from other minerals. If the separation is done in a way that loads the bitumen froth with mineral matter, examination of the retained mineral matter indicates that it is essentially the normal aggregate in which there has been a tendency to increase the finally divided portion. But when the separation is done so that only the minimum amount of mineral matter is retained by the bitumen, say less than 5% total mineral matter, then it is found that the mineral matter will mainly be fine with a much higher content of mica and heavy minerals.

The studies of the surface energy by which the bitumen is held to the sand have been of a relative nature. They have been in the form of comparisons of the ease of removing various bitumen from different types of aggregate when varying operating conditions such as temperatures, wetting agents and diluents. These empirical studies have led to the development of an efficient water separating process and the determination of the best range of operating conditions. With the present advances in the technique for securing the basic measurements of surface energy as between the bitumen and sand, it may be possible further to clarify the optimum technical conditions.

Field Plant

The Government plant at Bitumount on the Athabasca River has corresponded to a small commercial development in that area. The plant designed and operated to a capacity of over 500 barrels per day output, is entirely self-contained. Apart from having the bituminous sand quarry and the central processing units, including the separation plant and dehydration and distillation units, it has been fully supported by the necessary ancillary plants. These include the power plant, machine shop, laboratory, living accommodation for the staff, a river wharf and an airstrip. The main parts of the plant have not been winterized but are fully developed in every way for operation during the summer months.

The work at Bitumount has demonstrated that the hot water separation process can be carried out continuously and can be placed on a routine operating basis on a large scale. The operations have been recorded in the reports to the Board of Trustees of the Oil Sands Project. This practical demonstration of the hot water principle of bitumen separation from sand has provided an essential link between the results from pilot plant work and the results that are required for the consideration of a commercial sized development. The successful operation of the plant has made it possible to estimate with reasonable accuracy both the capital and direct operating costs that will be involved in handling comparatively large units. The units considered in this survey are 2,000 barrels per day each. That is four times the size of the Bitumount plant, a degree of expansion which can in this case be made with reasonable accuracy.

Commercial Sized Units.

With the knowledge and experience gained from the plant at Bitumount the tentative design has been prepared for a full size commercial separation plant. The hot water separation of

bitumen from sand is a surface reaction. Ideal separating compartments of different capacities will not be simply proportional in volume, but must present proportional surfaces per unit of feed. The depth of water that can be efficiently used is limited, and a definite amount of surface is required for the froth collection. In view of these conditions the design for the large commercial plant used in this survey has been developed as a series of units as mentioned above. There is good reason to assume that such units could be operated effectively in the light of the knowledge now available from the Bitumount operations. It is also probable that future developments will show methods of simplifying the battery of units, but for the present purposes such a plant gives assured operation and has permitted the development of costs which could be fulfilled in the first large scale developments.

The new design has included changes and simplifications wherever it has been felt possible from the process employed at Bitumount. In this way a pulper has been introduced in place of the screw conveyor, screens, etc., and the shape of the separation cell has been adjusted to simplify the sand disposal. The method of oil froth removal has been simplified and certain changes have been made in the process water settler.

With these major changes detailed consideration has also been given to each item in the processing to ascertain what variations or improvements could be applied within the overall principle that a reasonably proven operation only would be used for costing purposes.

The flow rates have been determined for each section and all the basic design conditions outlined including temperatures, material balances, reaction times, physical condition of the material in each section and in addition the total utilities. The heat balance is very briefly summarized in Table 1 for each section, while the material balance is summarized in Table 2.

Power and Fuel

A summary of the power requirements is given in Table 3, and of the steam consumption in Table 4. The readiness with which waste heat from any other process or power plant can be used in the hot water separation process is an important feature. Most of the low pressure steam required for heating will probably be available as exhaust steam from the power station. The fuel requirements for the separation unit have been estimated to be approximately 3.5% of the fuel produced in the plant.

Table 1

SUMMARY OF HEAT BALANCE FOR SEPARATION PLANT

Heat Entering—	
1. Bituminous Sand Feed—2000 tons at 40 deg. F.	7.2 x 10^6 Btu.
2. H.P. Steam to Hopper—24 tons at 150 psig.	57.2
3. L.P. Steam to Pulp—35.7 tons at 8 psig.	82.8
4. L.P. Steam to Water Heater—54.2 tons at 8 psig.	147.0
5. Raw Water to Driessen Cone Underflow—740 tons at 65 deg. F.	48.8
6. Raw Water to Tailings Pump—2400 tons at 65 deg. F.	158.4
	501.4
Heat Leaving—	
1. Oil Froth—386 tons at 197.1 deg. F.	70.0
2. Tailings—4814 tons at 88 deg. F.	383.8
3. Condensate from Water Heater—54.2 tons at 200 deg. F.	21.5
4. Radiation	25.3
	500.7

Table 2

SUMMARY OF MATERIAL BALANCE

1. Water—		
(a) Water Entering Separation Plant Unit:		
in Bituminous Sand	40	tons/day
in H.P. Steam	26.4	" "
in L.P. Steam	101.2	" "
in Make-up	3140.5	" "
	3308	" "
(b) Water Leaving Separation Plant Unit:		
in Tailings	3120	" "
in Oil	120	" "
in L.P. Steam	2.4	" "
in Condensate	65.5	" "
	3308	" "
2. Oils—		
(a) Oil Entering Separation Plant Unit:		
in Bituminous Sand	280	" '
(b) Oil Leaving Separation Plant Unit:		
to Storage	252	" "
to Tailings	28	" "
	280	" "
3. Sand—		
(a) Sand (and Clay) Entering Separation Plant Unit	1680	" "
(b) Sand (and Clay) Leaving Separation Plant Unit:		
in Oil	14	" "
in Tailings, from Oil Settler	14	" "
in Tailings	1652	" "
	1680	" "

Table 3

SUMMARY OF POWER REQUIREMENTS

Operation	Power For One Unit 2000 tons/day
1. Conveyor	20
2. Pulper	70
3. Sand Rakes in Separation Cell	2
4. Oil Mixer	0.5
5. Oil Settler Rakes	2
6. Recycle Pump	3
7. Sand Removal from Separation Cell	15.9
8. Tailings Removal	7.65
9. Make-up Water	0.66
10. Water from River	65.5
11. Oil Storage	10
	197.31

Table 4

SUMMARY OF STEAM CONSUMPTION

Operation	Pressure	2000 tons/day lb./hr.	Unit Basis tons/day
Storage Bin	High	2000	24
Pulper	High (Exhaust)	2975	35.7
Water Heater	Low (Exhaust)	5292	63.5
Condensate Pump	Low	200	2.4

FLUIDIZED PROCESSING

The principle of Fluidized Solids operation is very applicable to the bitumen developments. There are several basic reasons for this. The crude bitumen is virtually never entirely free from either solids as mineral matter or from water.

The solids constitute a serious hazard if the material is processed in a pipe still and if in any quantity they preclude pipe still operation. Such material can, however, be effectively handled in plants that use the solid fluidizing technique.

There is always an appreciable amount of water associated with the bitumen.[24] This is made up of the connate water from the formation together with the large amounts of water that become mixed in the bitumen during its separation, in water, from sand. The bitumen and water do not separate even when the mixture is held at an elevated temperature. There may be 40% or more water in relatively stable mixture with this bitumen.

It has now been shown that wet bituminous charging stock can be efficiently distilled in the fluidizing process. As the process thus allows the charging stock to contain both mineral matter and water and as it allows continuous operation its suitability and importance for use in bitumen processing is apparent.

The development of the pertinent fluidization data to the handling of the bituminous sands has come from two sources. One source has been the direct application (through the use of a pilot plant) of the principle to the bituminous sands by the National Research Council of Canada.[25] They have determined the yields obtainable, the operating conditions and have produced samples of oil from bitumen for further processing and testing. The other source of data has become available through the commercial plants in the oil industry that use the fluidizing technique. The commercial developments during the past 10 years have fully established the merit of the principle both technically and economically on a large scale. They have also made available data on the capital and operating costs for plants of the size required in the bituminous sands development.

The possession of the fluidizing data, on both this specific raw material and on industrial operations and costs has provided a most important section of the overall evaluation. Without it at present there is no proven economical link between the raw bitumen as recovered from the sand and a raw oil, free of water and mineral matter, that is capable of being taken over for further processing by conventional refinery processes. The importance of having such a link tor which general costs have been fully established and which has had the features peculiar to this operation tested will be readily appreciated.

The Universal Oil Products Company who have carried out the refining tests on the bitumen for many years are fortunately also designers and developers of the plants using the fluidized technique. They have now combined the results obtained by the National Research Council with their commercial experience from large fluidized plants and developed the capital and operating costs for those stages in the handling of this bitumen.

The commercial plants using the fluidizing technique are so well known and fully described in the literature that they do not require any review. The direct application of the fluidizing technique, however, to the bitumen is new and requires further description.

The National Research Council of Canada has studied two methods ot applying the fluidizing principle. In the first, oil was distilled directly from bituminous sand in a fluidized solids bed.

In the second the wet crude bitumen from the hot water separation process was used as charging stock to the fluidized still. The plant has been shown to be capable of handling either material successfully. The oil yields were similar, being in the order of 85% and the products are very much alike.

The oil produced is water-free and has the following properties:

Specific Gravity	0.960
Viscosity at 100 deg. F.	52 Kinematic Centistokes
Sulphur	4%
Distillation 50% over at	650 deg. F.
Asphaltene Content	0.5%

The Results from the National Research Laboratories

The results from the pilot plant are described in two sections.

Part One deals with the production of oil directly from bituminous sand feed.[26] The work has been completed and detailed data are available. Since this represents the general principle on which both types of operation are based a brief description is included in this Survey.

Part Two deals with work done on the dehydration and coking of the primary hot water

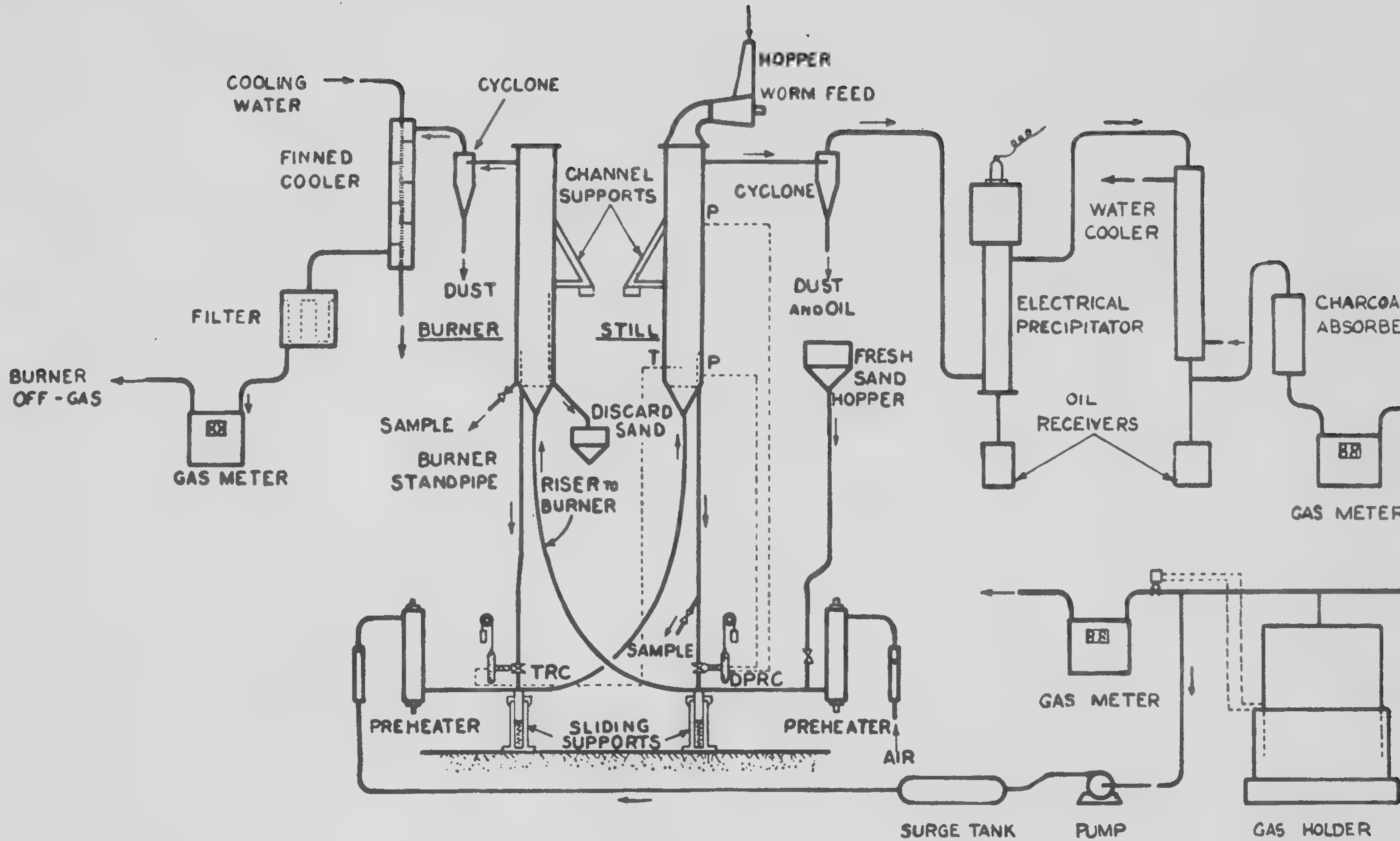


FIG. 9. PILOT PLANT LAYOUT SHOWING RECYCLE SYSTEM

separation product from the Alberta Government's plant at Bitumount. This work is not yet completed but sufficient progress has been made to confirm that the material can be satisfactorily processed in a fluidizing plant. Since this operation is a link in the sequence of processes used in this bitumen evaluation the results are included.

PART I.

DIRECT DISTILLATION OF BITUMINOUS SAND

When a gas is passed upwards through a bed of finely divided particles at sufficient velocity, the whole bed becomes violently agitated. The bed is said to become fluidized. From laboratory scale tests it was learned that when lumps of bituminous sand were fed directly into a hot (930 degrees F.) fluidized sand bed the following was found to occur—

(1) The oil distilled off immediately.

(2) The bituminous sand lumps broke down immediately into individual grains of free flowing sand that became thoroughly mixed with the bed.

(3) Some coke was formed and this appeared as a thin, closely adhering black film coating the surface of the sand particles.

(4) The oil formed was brown instead of black and it was much less viscous than the bitumen in the teed, indicating that considerable cracking had taken place.

(5) The formation of process gas also ind cated cracking.

(6) Good yields of oil were obtained.

Pilot Plant

A pilot plant was designed in the Council along the lines shown in figure 9. It consisted of a still burner together with the necessary controls and measuring equipment. Bituminous sand was fed continuously from a hopper by means of a worm into the top of the still which contained a heated bed of fluidized sand. The oil flashed off and was carried by the fluidizing gas, first through a hot cyclone where the dust was removed, then to an electrical precipitator and a condenser to remove the oil. The gasoline was removed by an activated charcoal scrubber and later recovered. At the same time that the oil was distilling off the risidual sand broke down into free flowing particles coated with coke.

This sand was withdrawn continuously down the still standpipe and blown by air into the burner where the coke was burned off to heat up the sand. Sufficient of this hot burnt sand was recycled to the still to supply the heat necessary for distillation. The remainder was discarded. Bed depth and temperature were controlled automatically.

Results

Work was done on bituminous sand from the Abasand and the Bitumount deposits which were believed to represent the two extremes of the field. In the former the bitumen was quite viscous and the sand very fine grained. In the latter the reverse was true. Screen analyses of the sand from the two sources are given in Table 5.

Table 5

SCREEN ANALYSIS OF EXTRACTED SAND

Mesh	Abasand	Bitumount
on 35	0.1	10.6
35-60	0.7	34.4
60-80	4.0	36.0
80-100	27.3	9.9
100-150	43.0	5.0
150-200	15.7	1.6
Through 200	8.2	1.6

Table 6 gives the significant operating data for two temperature series.

Table 6

PILOT PLANT OPERATING DATA

Feed—	Abasand				Bitumount			
Run No.	12	11	16	17	13	9	10	18
Duration Hrs.	10	10	6	6	6.6	10	10	5.5
Weight lbs.	830	864	453	500	704	886	854	435
Bitumen %	17.0	16.4	16.4	16.4	13.5	12.5	14.5	15.8
Water %	0.3	0.3	0.5	0.3	.35	.5	Nil	0.9
Rate lb./hr.	83	86.4	75.5	83	107	88.6	85.4	79
Oil Product—								
Col. U.S. gal.	14.3	14.2	6.7	7.2	9.9	12.4	12.8	6.4
Yield Vo. %	84.0	83.5	75.0	73.5	85.7	86.5	96.0	82.5
Solids %	0.1	0.25	Trace	Trace	Trace	Nil	Trace	Trace
(Settled Oil)								
Water %	Trace	Trace	Trace	Trace	Nil	Trace	Nil	0.1
Operation—								
Still Temp. deg. F.	925	977	1022	1067	932	950	977	1022
Still Dust lbs.	19.3	21.1	18.0	22.0	7.0	5.1	2.1	2.6
Burner Temp. deg. F.	1303	1286	1373	1436	1220	1320	1265	1400
Burner Dust lbs.	19.3	21.1	18.0	22.0	7.2	13.0	10.3	7.0
Recycle Ratio	2.9	4.4	3.8	5.0	4.4	4.7	—	3.9

Table 7 gives a materials balance.

Table 7

MATERIALS BALANCE

	Bitumount	Abasand
Feed In:		
Solids, lbs.	85.5	83.1
Water	0.5	0.5
Oil	14.0	16.4
TOTAL	100	100
Products Out:		
Sand Discard, lbs.	83.6	79.2
Still Cyclone Dust	0.4	.58
B.S. in Oil	.04	.89
Burner Cyclone Dust	1.4	2.40
Oil, lbs.	11.6	13.2
Coke, lbs.	1.4	2.1
Process Gas, lbs.	0.7	1.0

Table 8 gives the oil inspections for these runs.

Table 8

OIL INSPECTION

Feed:	Abasand				Bitumount			
Run No.	12	11	16	17	13	9	10	18
Reaction Temp.	925	977	1022	1067	932	950	977	1022
Density gm/cc	.954	.962	.959	.950	.961	.954	.961	.961
Viscosity kin. cstks.								
100 Deg. F.	68.0	52.0	21.9	11.5	62.0	52.0	—	41.6
210 Deg. F.	5.6	6.2	3.7	2.7	7.4	5.2	—	5.5
Distillation:								
I.B.P. Deg. F.	160	176	156	125	180	178	182	182
5%	280	338	245	215	308	426	412	412
10%	—	460	325	284	435	500	482	472
20%	585	575	487	417	540	580	558	448
30%	615	630	569	525	609	—	600	600
40%	638	660	614	596	645	662	630	637
50%	650	682	646	638	670	682	650	655
60%	662	700	660	668	692	710	662	680
70%	672	715	670	686	708	720	672	701
80%	670	730	682	707	714	728	670	720
Sulphur wt. %	4.0	—	—	—	—	—	3.9	4.0

SUMMARY

1. Yield

(a) **Oil** recoveries of 86% and 84% by volume were obtained for Bitumount and Abasand feed respectively. Abasand yields decreased but Bitumount did not with increases in temperature.

(b) **Coke**—8% to 13% by weight of the bitumen was obtained as coke.

(c) **Process Gas**—This was about 5% by weight (230 cu. ft. per bbl.).

2. Specific Gravity

Specific Gravity 0.960% (16.0 A.P.I.).

3. Viscosity

Up to 930 degrees F. the viscosity of the oils from both crudes was the same.

4. Distillation

Abasand feed was found most susceptible to cracking.

5. Sulphur

Sulphur was 5% in the feed and 4% in the product, irrespective of temperature or source.

6. Water

Bituminous sand feed contained 1% water which was readily settled from distillates.

7. Heavy Minerals

Traces of vanadium, silver and nickel were found in the distillate.

8. Composition

The asphaltene resin and oily material content are shown in attached graphs.

Table 9

EFFECT OF REACTION TEMPERATURE ON OIL COMPOSITION

Run No.	Temp. Deg. F.	Asphaltenes	Resins	Oily Material
Feed	Room	17.9	34.7	45
6	896	0.2	29	65
9	950	0.5	23	72
10	977	0.7	21	75
18	1022	1.0	19	79

The top row of figures gives the values for raw bitumen for comparison. The data indicate that a substantial amount of cracking has taken place during flash distillation of the bitumen in the fluidized solids still bed. Asphaltenes have been almost entirely eliminated, resins have been considerably reduced and there was a very marked increase in the oil material content.

Conclusions

1. The fluidized solids bed technique was used successfully to produce oil directly from bituminous sand.
2. Oil yields of 84 to 86% by volume (80.5-82.5% by weight) were obtained.
3. Considerable cracking within the still resulted in a product with properties that differed markedly from those of the original bitumen.
4. The heat requirements were almost entirely met by combustion of the by-product coke and and process gas. A net recovery of at least 80% by volume was indicated.

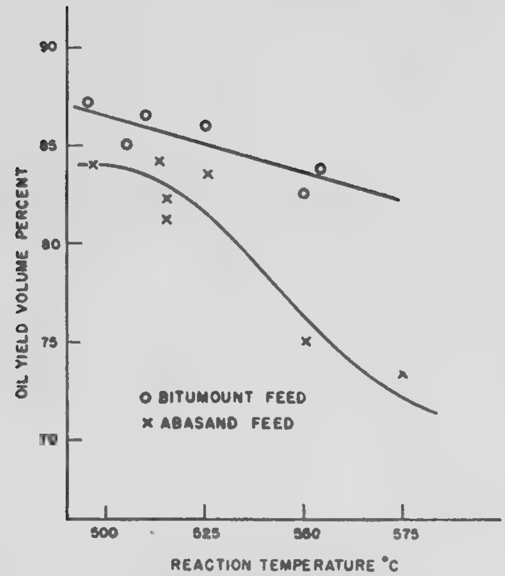


FIG. 10. EFFECT OF REACTION TEMPERATURE ON OIL YIELD

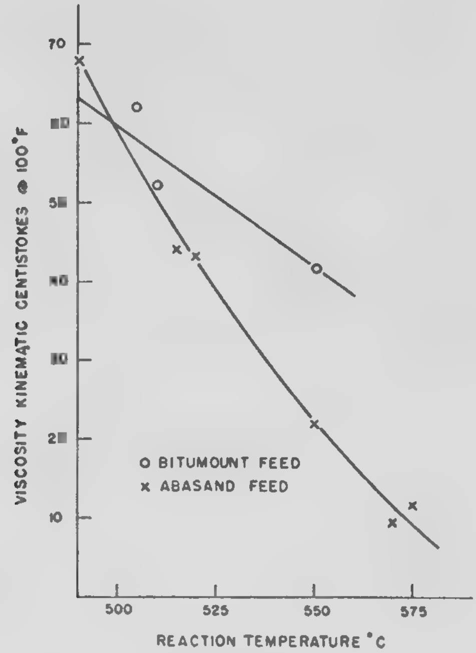


FIG. 11. EFFECT OF REACTION TEMPERATURE ON OIL VISCOSITY

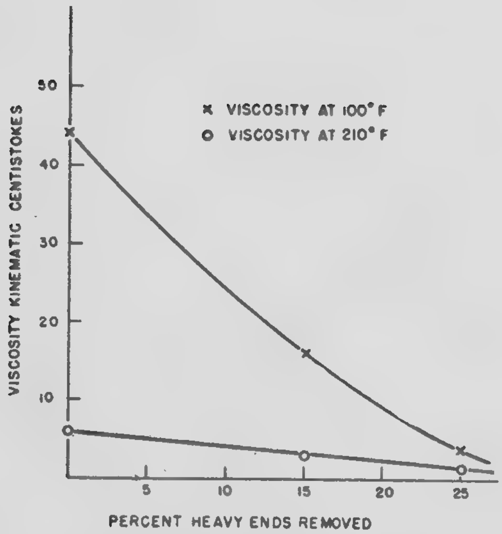


FIG. 12. EFFECT OF REMOVAL OF HEAVY ENDS ON VISCOSITY

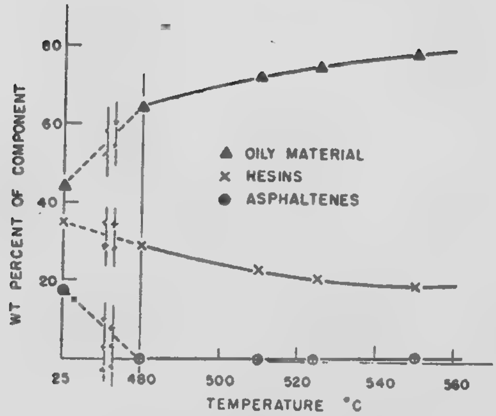


FIG. 13. INFLUENCE OF REACTION TEMPERATURE ON COMPOSITION OF OIL FROM BITUMOUNT FEED

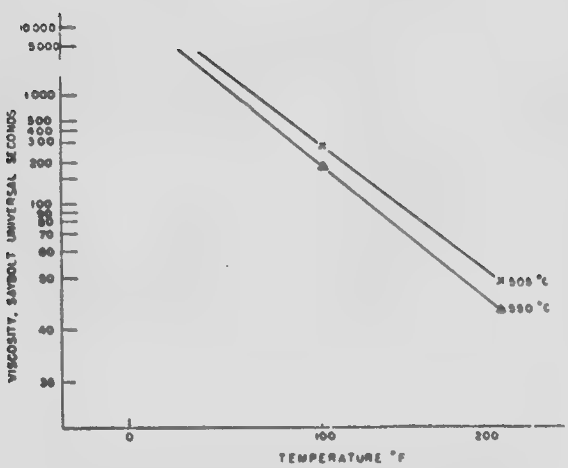


FIG. 14. VISCOSITY CHART FOR OIL FROM BITUMOUNT FEED

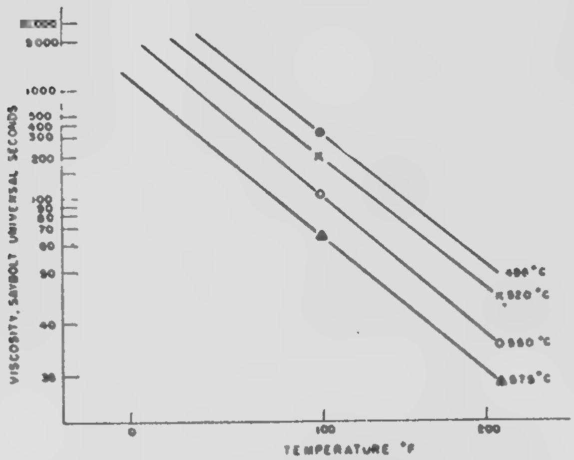


FIG 15 VISCOSITY CHART FOR OIL FROM ABASAND FEED

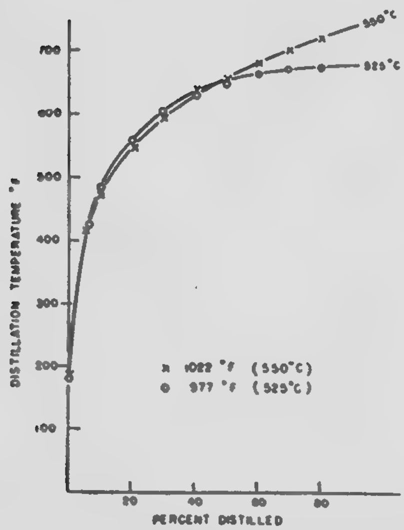


FIG. 16. EFFECT OF REACTION TEMPERATURE ON DISTILLATION CURVE—BITUMOUNT FEED

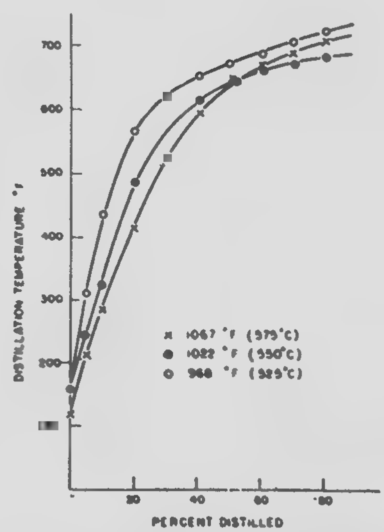


FIG. 17. EFFECT OF REACTION TEMPERATURE ON DISTILLATION CURVE—ABASAND FEED

PART II

DEHYDRATION AND COKING OF WET CRUDE BITUMEN FROM THE BITUMOUNT HOT WATER SEPARATION PLANT WITH FLUIDIZER TECHNIQUE

Introduction

Treatment of bituminous sand at the Bitumount plant involved three operations—

(1) Primary hot water separation to yield a bitumen containing about 33% water and 7% solids.

(2) Dilution with a light oil followed by flash dehydration to remove the water.

(3) Distillation to recover the light oil diluent to produce a dry bitumen of high viscosity.

The possibility appeared attractive that the Fluidized Solids-Still described in Part I might prove satisfactory for treatment of wet bitumen such as had been produced at the Bitumount plant, as the work with large fluidizing plants in the oil industry had indicated their possibilities when using wet charging stocks.

The advantages that would be gained through the successful application of this technique to the wet bitumen have been indicated previously in the way of avoiding the use of a pipe still to process liquid-solids mixtures, and also providing a simple means of dehydration. To those, should now be added the elimination of the losses of diluent oil, that of necessity had been associated with the other dehydration methods.

The National Research Council undertook to test the possibility of using the wet bitumen as charging stock for the fluidizing process. Their program was based on a pilot plant in which they would first develop suitable arrangements to prove the principle of the operation. When the theory of the operation was substantiated the investigations would be directed to the following.

1. The establishment of oil yields and plant capacities.
2. The inspection of the oil samples produced.
3. The materials, heat balance and pertinent data to permit the commercial evaluation of the process.

This work is summarized in the following sections and is given in some detail because of its being both a new development and of fundamental importance to the bitumen evaluation.

1. Pilot Plant Developments

In the work on bituminous sand a worm feed located above the still dropped the material directly into the top of the still bed. The still bed had been fluidized by recycled off-gas. The plant was modified to make it possible to pump wet crude bitumen directly into the bottom of the still. The steam and oil vapor that formed when the feed hitthe hot sand of the still bed were meant to serve as the fluidizing gas. Preliminary work included introduction of the feed at the base of the still riser. Technical difficulties mainly due to coke formation prompted the relocation of the feed line to the base of the still. Satisfactory feeder equipment was developed.

2. Establishment of Oil Yields and Plant Capacities

In order to determine the yields at various still temperatures a series of runs was made similar to those described in Part I except that wet crude bitumen was used as the charging stock. The charge consisted of approximately bitumen 66%, water 30% and solids 4%.

Table 10

OPERATING DATA

Run No.	B-37	B-39	B-40
Charge Stock: Bitumen, %	66.34	66.10	64.06
Water, %	30.16	30.80	32.98
Solids, %	3.50	3.10	2.96
Antifoam added ppm.	15	15	15
Charge Rate, lbs./hr.	12.7	14.3	16.9
Total Charge, lbs.	48.37	85.75	101.34
Still Temp. Deg. F.	983	997	1044
Burner Temp. Deg. F.	1396	1372	1490
Charge Temp. Deg. F.	69	72	69
Still Bed Depth, inches	30.0	30.6	30.7
Burner Bed Depth, inches	36	36	36
Still Gas Rate, ft./sec.	0.862	1.004	1.172
Burner Gas Rate, ft./sec.	0.99	0.99	1.00
Oil Yield, lbs.	27.14	46.09	52.59
Oil Yield, % by volume	88.56	84.35	83.43
Coke Yield, lbs.	2.59	4.59	5.28
Coke Yield, % by weight	8.1	8.1	8.1
Process Gas, cf/bbl. of bitumen	223	—	285
Process Gas, % by weight	4.92	—	6.18
Dust Yield: Burner Cyclone and Filter lbs.	1 26	1.58	1.40
Still Cyclone (coke free), lbs.	0.51	1.55	1.71
In Distillate Oil, lbs.	0.12	0.31	0.81
Water Yield, lbs.	13.37	24.27	34.14

Yields

The maximum oil yield was 88% by volume at 983 degrees F., while at 1044 degrees F. it dropped to 83% by volume. The results are shown in Table 10. The solids in the charging stock were high in finely divided clay and tended to leave the plant as dust rather than with the mineral aggregate. About one-half this dust was collected in the burner cyclone and filter while the remainder left the still with the oil vapors. From 70% to 85% of this was removed by the external hot cyclone as a dry powder. The solids in the settled oil were about 0.1%. In this connection it is to be noted that no facilities were available for the continuous fractionation of the condensate and recycling of the heavy ends which carry the major portion of the minerals.

The yield of gas was estimated to be between 225 and 290 cu. ft. per bbl. dependent on the still temperature. The water from the charging stock was readily separated from the condensate.

Table 11

MECHANICAL ANALYSIS OF BED SOLIDS

Following Run No.	B36	B37	B39	B40
60 Mesh	10.0	10.3	10.8	9.1
60 - 80 "	13.2	15.1	15.7	12.4
80-100 "	27.7	28.1	29.8	30.6
100-150 "	36.1	35.6	32.6	36.1
150-200 "	11.9	10.4	10.0	11.0
200-325 "	1.1	0.7	0.6	0.6
325 "	0.0	0.0	0.0	0.0

Table 12

INSPECTION OF DEHYDRATION-COKING DISTILLATE OIL

Reaction Temperature, Deg. F.	983	997	1044
Specific Gravity at 60 Deg. F., as received	0.957	0.964	0.971
Specific Gravity at 60 Deg. F., solids free	0.955	0.960	0.962
Gravity, Deg. API, solids free	16.7	15.9	15.6
Water, %	0.2	0.2	0.2
Solids, % as received for analysis	0.39	0.67	1.21
Solids, % as plant yield (calculated)	0.45	0.67	1.50
Total Sulphur, %	4.1	4.2	4.2
Asphaltenes, %	1.2	1.6	2.4
Conradson Carbon, %	6.0	6.1	8.6
Viscosities, Kinematic at 70 Deg. F.	150	157	67
Viscosities, Kinematic at 130 Deg. F.	28.8	27.5	17.4
Distillation I BP	146	159	150
5	352	358	276
10	458	448	361
20	557	536	498
30	600	595	566
40	630	625	609
50	646	641	635
60	662	650	652
70	677	666	661
80	686	674	662
Specific Gravity at 50% Recovery	0.889	0.889	0.881

Conclusions

1. It has been shown that wet bitumen from the hot water separation process may be dehydrated and coked simultaneously and continuously by flash distillation with a fluidized solids bed.

2. Wet oil from the Bitumount location gave a liquid yield of coker distillate of at least 83% by volume, a coke yield of about 8.02% of the bitumen charge, and a process gas yield of about 250 cu. ft./bbl. of bitumen.

3. The water in the charging stock was readily separated from the oil distillate by conventional means. The coker distillate, as recovered, contained only 0.2% water.

4. No build-up of dust from the feed was observed in the solids bed.

5. The distillate oil was found to be approximately the same as that obtained from the direct flash distillation of bituminous sand. Solids content of the oil was somewhat higher. The gravity of the distillate oil was about 16 degrees API.

INVESTIGATIONS AT THE MINES BRANCH, OTTAWA

The Mines Branch have carried out a great deal of investigational work on the Bituminous Sands and have contributed a vast amount to the knowledge of the subject.

The Branch have also taken a very active part in this Government survey of the research, investigation and processes that are pertinent to the recovery of the bitumen and its evaluation. Their past findings have been reported in the Dominion Government publications and in the Technical Journals. It is only necessary here to include a record of the nature and status of the present work in the Branch on the bitumen. The three main fields of research recorded are, the Cold Water Separation Process, the Fundamental Work on the Bitumen and the Hydrogenation and Desulphurization Projects.

A Review of Current Activities of the Mines Branch, Ottawa, Relating to Separation and Refining of Bitumen

I. Cold Water Separation

Introduction

The cold water method of separation[27] derives its name from the fact that it is conducted at a temperature of about 77 degrees F. Bitumen can be separated from sand at this relatively low temperature if a diluent is added at the beginning of the procedure. The diluent lowers the viscosity

of the bitumen so that it can be removed from the sand grains and reduces its specific gravity so that it will rise to the surface of the water. The method is believed to have been used by Abasand Oils Ltd. in 1944, but the Horse River Plant of that company was destroyed by fire in 1945 and records of the experimental work were lost. Studies of the cold water method have been carried on by the Mines Branch, first on a laboratory scale and later in a small pilot plant.

Preliminary Experiments

The laboratory-scale experiments were applied to a study of the principles of the method. Briefly it consists in adding a diluent, an alkaline reagent and water to bituminous sand; the mixture is disintergrated in a ball mill and after addition of more water is agitated and allowed to settle. The amount of oil collected at the surface of the water at temperature around 77 degrees F. is about 98 percent of the total bitumen and diluent charged. The laboratory experiments included investigation of the effects of hydrogen ion concentration upon the recovery of oil.

Pilot Plant

Having established a procedure by which high recoveries of bitumen could be obtained, it appeared advisable to test the method further in a small pilot plant. The major purpose of the pilot plant investigation was to develop an operating technique that could be made the basis for a large scale operation.

It was found that four distinct operations are needed to recover a large proportion of the bitumen in the form of an oil having low enough contents of water and inorganic solids to be acceptable for the subsequent distillation. These operations are as follows—(1) mixing and disintegration of the charge of bituminous sand, water, diluent and reagents; (2) addition of water to the disintegrated charge and agitation to liberate bitumen and diluent from the sand; (3) classification of the agitator discharge into sand and oil slurry fractions; (4) settling of the oil slurry to remove water and finely divided inorganic matter. Following these operations the cycle was completed without the use of extraneous diluent by distilling the oil product and returning the volatile fraction to the mixing and disintegration step.

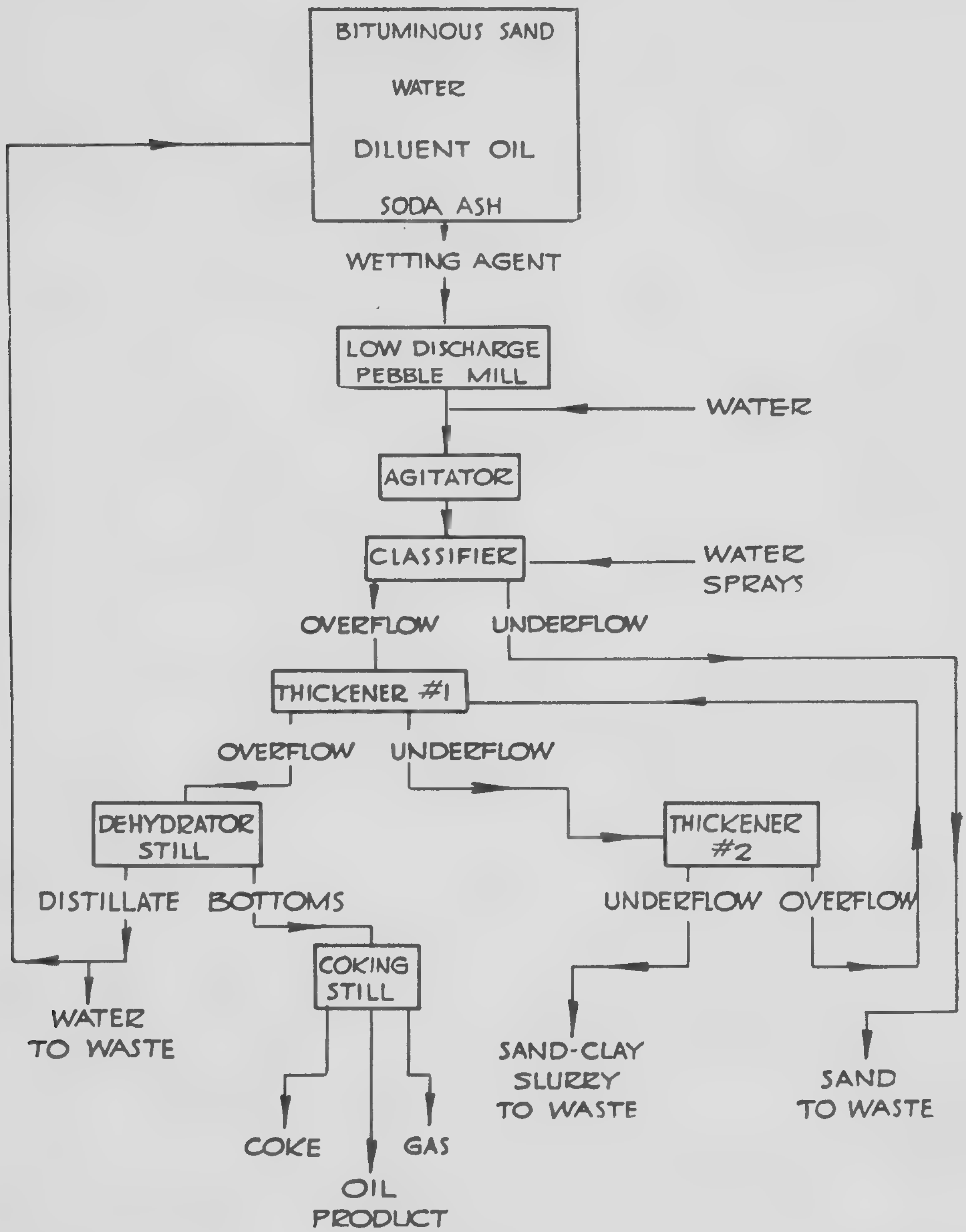
It was found to be feasible to use ore-dressing machinery of standard design for all four of the operations. Special distillation equipment was, however, designed for recovery of diluent from the oil product which contained water, inorganic solids and asphaltenes. A flow diagram indicating the equipment used is shown in Figure 18. Performance of the hydrometallurgical section of the pilot plant was technically satisfactory. As applied to bituminous sand from the Horse River area the procedure gave a net recovery of bitumen, allowing for replacement of lost diluent, of 95 per cent. The corresponding recovery from bituminous sand from the Bitumount area was 90 per cent. The thickener overflow had water and inorganic solid content of 25 and 2.5 per cent respectively. The equipment used for dehydration, diluent recovery and coking was not of conventional design. Distillation of the oil product from the thickener is necessary for dehydration and recovery of diluent. Because of the asphaltic nature of this oil and the fact that it contained water and inorganic solids it was decided to avoid heating it in pipes. Two types of distillation and coking were developed on a laboratory scale which were satisfactory for dehydration and coking respectively. Further mention is particularly made of the results of the Quench type of coking because of the industrial application of that principle.

The performance of the Quench coking apparatus was satisfactory. Based on the bitumen charged the yields by weight of oil, coke and gas were 75, 16 and 6 per cent respectively. The oil product was free from suspended inorganic solids and had an A.P.I. gravity of about 20. The coke had good physical properties, a heating value of about 14,000 B.T.U.'s per pound, a mineral matter content of 8.1 per cent and a sulphur content of 6.9 per cent.

Weight and Energy Balances

Although operation of the small pilot plant does not constitute complete development of a process based on the cold water separation principle, it was desirable to work out a weight and energy balance based on a bituminous sand input of 20,000 cu. yds. per day for inclusion in this report. The balanced diagram is shown in the attachment to this report, and the data and assumptions used in preparation of the balances are given in the accompanying tables.

FLOW DIAGRAM
COLD WATER SEPARATION PROCESS
(FROM MINES BRANCH, OTTAWA)*



* MR. L. E. DJINGHEUZIAN

FIGURE 18

Laboratory Study of Some Basic Factors in Cold Water Separation

Previous experimental work at the Fuels Division of the Mines Branch suggested that wetting agents might play an important role in the separation of bitumen from sand. In a laboratory modification of the cold water process Pleet and Montgomery tested 55 organic wetting agents including members from the anionic, nonionic and cationic classes. The nonionic class as a whole appeared to yield the most satisfactory separation of the oil phase from the sand. The most suitable member of this class of wetting agents was found to be Span 40 manufactured by the Atlas Powder Co. The most suitable wetting agent was considered to be the one which yielded the lowest values of water and inorganic matter in the oil phase with the smallest loss of bitumen in the sand tailings.

The pH of the water was found to have a profound influence upon the cold water separation process. While it was found possible to reduce either the water or mineral matter of the oil phase by varying the pH of the water, it was not found possible simultaneously to reduce both these quantities to the levels obtainable with the best wetting agents.

2. Chromatographic Analysis of Bitumen

Two analytical schemes were employed[28] to resolve bitumen into its component classes of compounds. In the event that one method failed it was hoped that the other would give some useful information. A diagram illustrating the schemes is shown in Figure 19.

Some of the salient results of the analysis are itemized below—

(a) The lowest molecular weight material in the bitumen, constituting 1.2% of the total, had a molecular weight of 172.

(b) Approximately 21.6% of the bitumen is distillable at 230 degrees C and 0.2 mm Hg. More bitumen may be distilled if the temperature is raised. The above temperature and pressure were selected to avoid thermal cracking. The fact that no olefins were detected by the chromatographic analysis of this oil substantiated the view that no cracking had occurred.

(c) The main distillate could be chromatographed on silica gel to yield a paraffin-cyclo paraffin fraction and an aromatic and sulphur containing fraction of almost equal size.

(d) The paraffin-cyclo paraffin fraction contained almost no linear paraffins as waxlike material.

(e) Little success was achieved in the chromatographic analysis of the pentane soluble fraction of the bitumen until the resin fraction was removed with Florex. It is considered possible that this may be done by employing a large ratio of silica gel to pentane soluble bitumen.

(f) The oil fraction was rechromatographed on silica gel using methyl cyclohexane as the solvent. The procedure followed was that of Clerc, Kincannon and Weir.[29] The fractions were characterized by the refractive index and dispersion, and are subject to revision pending more detailed ring analysis.

3. Hydrogenation

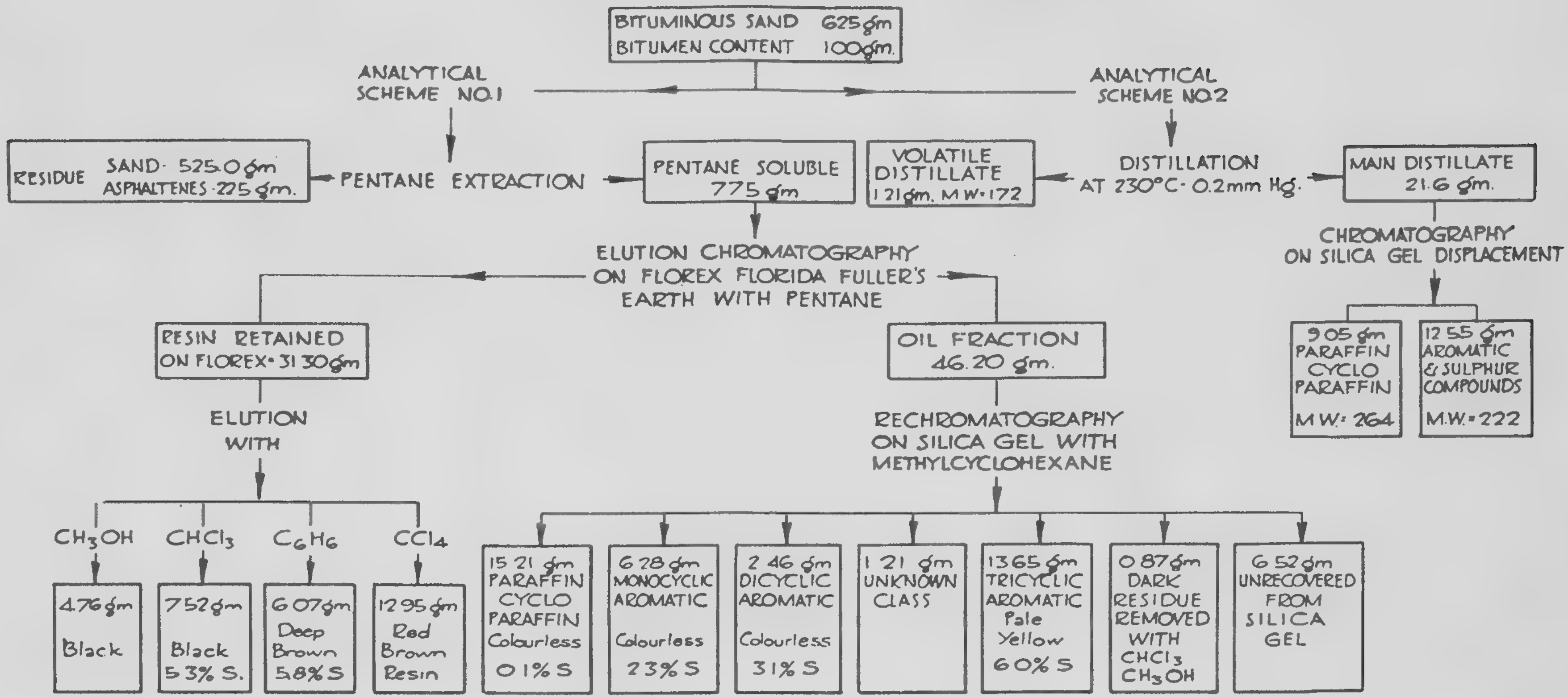
A plant is under construction at the Mines Branch for the study of basic factors in the hydrogenation of oils, especially in the range of very high pressures.

A study is also being started at once of the mild hydrogenation of the coker distillates from the bitumen. Hydrogenation is the most economical means at present of reducing abnormally high sulphurs such as the 4% in the coker distillate to an acceptable quality. Hydrogenation of this kind is under active consideration by a number of companies for various oils from normal crudes. The specific phase of the industrial approach, which the Mines Branch proposes to investigate is to test the application of some of the procedures to this bitumen coker distillate, giving particular attention to the possible effect on hydrogenation of the metals which are known to be present.

THE REMOVAL OF SULPHUR FROM THE BITUMEN

The importance of the sulphur in the oil products has been noted in Chapter I when dealing with the bitumen as a raw material for evaluation. Now when considering Processes, attention is given to the removal of the sulphur and also the significance of its recovery, particularly in so far as it could affect the economics of a bitumen development project.

SUMMARY OF CHROMATOGRAPHIC ANALYSIS OF BITUMEN (HORSE RIVER)
(FROM MINES BRANCH, OTTAWA)*



ASPHALTENES DETERMINED BY PENTANE EXTRACTION BY DR. M. L. BOYD ON ABASAND BIT. SAND - 22.5%
ASPHALTENES DETERMINED BY SEYER ON ELLS SAMPLE FROM HANGING STONE RIVER EXPOSURE, WINTER 1914-15 - 22.5%
ASPHALTENES DETERMINED BY METHOD OF KATZ (CAN. J. RES. 10444, 1934) BY DR. M. L. BOYD - 18.3%

* DR. D. S. MONTGOMERY

FIGURE 19

The amounts of sulphur involved are considerable. This is quickly illustrated by reference to the square mile, (section 23, township 92) which is used as the basis for the field estimating in this survey. Over that section there is an average of 120 feet of bituminous sand, with 14% of bitumen that contains 5% of sulphur. Thus that square mile contains approximately 1,500,000 tons of sulphur. The proposed refinery procedure for the development of the bitumen would lead to a recovery of slightly over 900,000 tons of elemental sulphur from the above amount, which it may be mentioned is about 15% of the annual world consumption.

The removal of the hydrogen sulphide gas following hydrogenation of the distillate is necessary. That is because the amounts of sulphur are too great to permit the direct sale of the gas with the sulphur in it, and at the same time the sulphur would be a serious public nuisance if allowed to escape into the atmosphere. Thus the hydrogen sulphide either has to be disposed of by burning or recovered if a suitable market is available. The recovery from all technical aspects is entirely practical.[31] The feasibility of economically converting hydrogen sulphide to elemental sulphur is fully established by the Girdler process. The sulphur gas could be converted directly to sulphuric acid or it could first be converted to elemental sulphur. The percent present justifies the principle of recovery for the bitumen operations in general and the amount of 140 tons per day places the estimated plant well within the range of economic operations. The sulphuric acid market in Western Canada is limited, and since elemental sulphur is more easily shipped the production would be in that form.

The Dominion Bureau of Statistics' records give the following facts in regard to the Canadian sulphur position.

	1947	1948	1949
Production of Sulphur in Pyrites and Smelter Gas, Tons	221,000	229,000	249,000
Imports, Sulphur, Tons	361,000	354,000	291,000
Exports of Sulphur as Pyrites, Tons	56,000	50,000	92,000
Consumption of Sulphur in Canada, Tons	323,000	328,000	no data yet

The great bulk of the Canadian consumption of sulphur is by the woodpulp industry. The determination of the potential Alberta sulphur market at present, therefore, becomes largely a determination of the magnitude of the available woodpulp market. That is the market that could be reached before the cost of transport, added to the production cost exceeds the price of imported sulphur.

The Canadian pulp production West of Sault Ste. Marie that would consume sulphur is estimated to be about 470,000 tons annually. Since almost all the above tonnage is sulphite pulp, it is assumed that approximately 1/10 of a ton of sulphur is used per ton of pulp or that in that area the woodpulp industry would use in the order of 50,000 tons of sulphur annually.

The sulphur would be shipped as a loose powder in bulk and rail rates have not been formally established for the shipment of that commodity in such quantities.

The cost of a plant in Alberta to produce elemental sulphur from H_2S commencing with a fractionated H_2S stream and producing 140 tons of sulphur per day is estimated to be approximately one million dollars. The 20,000 bbl. per day processing plant for bitumen would produce about 50,000 tons per year of potential sulphur.

The production costs will vary with each specific installation depending appreciably on the extent to which it can be co-ordinated into other refinery operations so as to attain the most efficient use of fuels, labor, etc. A general estimate has been prepared placing depreciation at 10%, insurance at 2½%, maintenance at 5%, which have been found suitable for sulphur plants elsewhere. The operating costs on this basis including the direct operating costs, insurance, maintenance, utilities, labor, field costs and losses and when debiting the plant with H_2S at its fuel value, together with interest on the capital investment would result in a total cost of approximately $8.50 per ton of sulphur.

The thorough study of the possible freight rates from Edmonton, in conjunction with the estimated production costs and market prices of sulphur, indicates that at least the Canadian market from the Sault west could be efficiently supplied from Alberta by such a plant.

The primary purpose of the study here is to determine what effect sulphur recovery could have as a by-product credit on the production cost of oil from bitumen. The proportions of recoverable sulphur that have been shown here are such that a three dollar per ton profit on the total sulphur production would yield a by-product credit sufficient to reduce the cost of all the total oil produced by two cents per barrel. It is therefore seen that not only is the recovery of the sulphur technically and economically feasible as a sulphur development in itself, but that its magnitude is such that sulphur can have an appreciable effect on oil production costs. The amount of sulphur by-product credit that can be assumed however, in any estimate on the cost or profitability from a bitumen development is dependent on the extent of the open sulphur market that can be definitely secured and in that connection the present rather limited market has been noted.

PIPE LINE TRANSPORTATION FROM THE PLANT TO EDMONTON

The pipe line required to transport the distillate produced would be 8 inches in diameter and approximately 255 miles long. It would weigh nearly 18,000 tons. The line would largely traverse undeveloped country. It would cross a good deal of muskeg similar to that which lies along the railway between Edmonton and McMurray. Pipe lines that are now built and successfully operated through comparable country, are either buried in the normal pipe line trench or have a mounding over the line.

The temperature in the line and the viscosities to be encountered directly effect the capital and operating costs. With reference to the maximum viscosity which can be pumped efficiently, generally speaking, pipe liners try to avoid prolonged pumping in the zone of stream line flow. The Canol Line in the far North[32] was a four-inch-above-ground development which went over summits as high as 5,000 feet and was operated for over a year. The minimum oil temperature recorded at any one of the 10 pumping stations was minus 19 degrees. Most stations had a minimum of about minus 7 or minus 8 and a few never fell below zero.

The snow and other cover on the line has naturally a great deal to do with the temperature. In the case of the line required for this survey 3 pumping stations have been included in the estimate, and as indicated it would be a fully covered and protected line.

A curve has been plotted by the Interstate Commerce Commission from the rates on file for trunk pipe lines. The possible line under consideration here however, due to its general location and nature of the surface soils, will be both more difficult to build and somewhat more expensive to operate than those commonly listed. A rate has been estimated for this line of 28¢ per barrel which is believed will be suitable to cover the costs of operating the line and the intransit storage if operated to full capacity, and permit the writing off of the whole line in 20 years time.

PROPANE EXTRACTION OF WET OIL FROM HOT WATER SEPARATION

One of the methods used to prepare gas oil feed stock for catalytic cracking from reduced crudes is known as propane deasphalting.[33, 34, 35] This method is used for this purpose in a number of commercial refineries, and the process as described involves contacting the reduced crude with appropriate amounts of propane in the liquid phase at moderate temperatures, gravity separation of the two resultant phases (a) the light solution of gas oil in propane and (b) the heavier asphalt, followed by recovery of propane from the gas oil and asphalt components.

On the basis of the above proven experience, it was thought that it might be feasible to apply propane extraction to the bitumen. A sample of wet oil prepared by the hot water separation process, and containing 28.6% water was contacted with six volumes of propane in a batch type apparatus, and after solution equilibrium was reached the two phase layers were separated. After removal of propane from each of the layers, the partition of water and hydrocarbon between the two layers was as follows—

	Wt. % of Wet Oil	% of Dry Bitumen Wt. %	Vol. %
Gas Oil Layer			
Dry Gas Oil	37.2	52.1	56.6
H_2O	0.6	--	--
Asphalt Layer			
Dry Asphalt	34.2	47.9	43.4
H_2O	28.0	--	--
	100.0	100.0	100.0

Nearly all of the water was separated with the asphalt which when cool was described as being quite hard and brittle.

Inspections of the original dry bitumen and separated gas oil were as follows—

	Dry Bitumen	Gas Oil Product
Sp. Gr.	1.0328	0.9509
Deg. API	5.5	17.3
Viscosity		
Furol Seconds at 210 Deg. F.	110	--
Universal Seconds at 100 Deg. F.	--	374
Wt. % Sulphur	4.89	3.15
Wt. % Nitrogen	0.43	0.13
Wt. % Conradson Carbon	17.88	2.53
Pentane Insoluble, %	22.98	1.32
Cold Test, Deg. F.	50	
ASTM, H_2O, %		1.7
Characterization Factor	11.05	11.4

A small scale catalytic cracking test of the gas oil indicated gasoline yields of the same order as obtainable from Mid-Continent gas oils, but the catalyst deposit was about twice as high. The high catalyst deposit yield was due partly to the nature of the gas oil and partly to the high carbon residue content of 2.53%.

Because the yield of deasphalted gas oil was so low (56%), no economic studies of this method of treatment of the separated bitumen were made. Variations in the propane to oil ration, or in the extraction temperature had no measurable effect on the yield of gas oil from the bitumen.

The principle of propane extraction has thus been established for commercial plants and for this specific material in so far as the technical aspects are concerned. Operations with the wet bitumen however, would introduce a number of unusual problems in regard to the disposal of the mineral matter which would entail additional operating costs to those commonly experienced with propane extraction processes.

HYDROGENATION OF COKER DISTILLATE

General

The coker distillate as produced contains about four percent sulphur. When the distillate is subjected to normal refinery processing without prior desulphurization the products made practically all contain appreciably greater amounts of sulphur than are encountered in the corresponding type of fuel made from crude oil. The sulphur could be removed from the separate products by treating each to the extent necessary to attain its own maximum sulphur allowance, or it can be removed from the raw distillate direct by mild hydrogenation. By the hydrogenation method a sweet oil for all further processing is produced and the subsequent processing corrosion problems are also avoided.

The degree to which hydrogenation can be most economically carried is dependent on the associated operations and products in the refinery under consideration. The practice has been assumed in this survey of complete sulphur removal in order to ensure the production of products that can be evaluated on an open market, irrespective of the sulphur that it might be possible to leave in some operating programs. In cases where high amounts of sulphur can be tolerated the practice might be followed of either limited removal by hydrogenation from the gas oil or the practice might be used of applying total sulphur removal from a percentage of the total throughput and then blending back with raw high sulphur oil to the sulphur limits. If the objective was to produce a charging stock for subsequent operations corresponding to high sulphur crudes a major refinery saving could be made in this way.

The hydrogenation costs are fully tabulated in Chapter III as a part of the total costing and evaluation of processing the bitumen oil. The total cost will be seen to be slightly over 80¢ per barrel.

Hydrogenation is one of the major tools in the processing and hence before approaching the summarization of operations it is necessary to review the most pertinent aspects of the mild hydrogenation process as applied to this oil.

RESULTS FROM MILD HYDROGENATION

In a laboratory scale operation a sample of fluidized coker distillate was hydrogenated so that its sulphur content was reduced from 4.06% to 0.26%, with a hydrogen consumption of 1000 cubic feet per barrel of distillate. At the same time, its olefin content was reduced from 81% to 16% and its API gravity increased from 16.0 to 26.2. The total observed hydrogen consumption can be resolved into requirements to:

(a) Saturate olefins, so that they are reduced from 81% in the feed to 16% in the hydrogenated liquid

(b) Combine with sulphur to produce H_2S

(c) Saturate the free bonds remaining when sulphur is removed from a molecule

(d) Combine with small amounts of nitrogen and oxygen in the coker distillate.

(e) Effect a small amount of hydrocracking.

Calculations show that the first three of the above items account for nearly all of the observed hydrogen consumption.

The Production of Hydrogen

The production of hydrogen by the methane reaction with steam followed by carbon monoxide removal has been applied. A hydrogen requirement of 20 million S.C.F. per day has been estimated. The Girdler process has been applied to this operation and the costs developed are tabulated here indicating a manufacturing cost of 25¢ per thousand cubic feet of hydrogen.

Girdlers have pointed out that if natural gas purification apparatus must be provided the capital cost of the plant is increased about 10%. The natural gas from the Leduc, Redwater and Lac la Biche fields is free of hydrogen sulphide.

COSTS OF MANUFACTURE OF HYDROGEN
FOR 20 MMCFD
PLANT INVESTMENT COST IS $3,000,000

Maximum Impurities: 0.2% CO; 0.1% CO_2; 1.1% CH_4

	Quantity MCF of H_2	Cost $/MCF of H_2	%	%
A. Direct Manufacturing Costs				
1. Natural gas for process at 10c/MCF	250 SCF	$0.025	13%	
2. Natural gas for fuel at 10c/MCF	214 SCF	0.021	11%	
3. Steam at 250 p.s.i.g. at 24c/1000#	250#	0.06	32%	
4. Cooling Water at 2.5c/1000 Gal.	1500 G	0.038	20%	
5. Catalyst and chemicals		0.02	11%	
6. Operating Labor— (2 operators at $1.65) (2 helpers at $1.40)		0.007	4%	
7. Maintenance Labor and Materials		0.015	8%	
Total Direct Manufacturing Costs		$0.186	100%	74%
B. Indirect Manufacturing Costs				
1. Depreciation at 10% investment costs/Yr. (Assuming plant to deliver 20 MMCFD for 365 days per year)		0.041	63%	
2. Taxes and Insurance at 2½% Invest. Cost/Yr.		0.010	15%	
3. Overhead (local) and Administration 50% of total of (a) Direct Labor (operating Lab. plus 15% for Supervision) (b) Maintenance Cost		0.008	12%	
(c) Operating Supplies (20% of Maint. Cost)		0.002	3%	
Total Indirect Manufacturing Costs		$0.065	100%	26%
Total Manufacturing Costs Without Credits		$0.251		100%
C. Credits				
1. For CH_4 in H_2 stream which might be recycled to H_2 manufacture at 10c/MCF Assuming 1% CH_4 in H_2 product stream	10 SCF	0.001		
2. Other by-products				
Total Manufacturing Cost less Methane Credit		$0.250		

ANALYSIS ALBERTA NATURAL GAS

	Leduc	Redwater	Lac la Biche
Hydrogen Sulphide	Nil	Nil	Nil
Carbon Dioxide	0.30% (orsat)	Nil	Nil
Nitrogen	3.61	2.50	2.91
Methane	87.90	92.86	96.83
Ethane	4.63	3.07	0.16
Propane and Heavier	3.56	1.57	0.10

The production of the above typical dry gases from that area, suitable for hydrogen production, is in such volume that production costs have been developed on the assumption that hydrogen sulphide removal before hydrogen manufacture is not necessary.

Type of Process

It is the intent of the hydrogenation step to remove sulphur, oxygen and nitrogen compounds from the coker distillate, and generally to upgrade the material by saturation at mild hydrogenation conditions so that the hydrocracking decomposition reactions are held at a minimum.

The simplified flow diagram of the sequence of processes used in Chapter III shows a possible arrangement of equipment to accomplish this type of mild hydrogenation. Only the major process flowing streams are shown; instrumentation, valves, utility lines, process control, by-passes and other such items necessary for plant operation have been omitted. Furthermore, the details of the reactor section arrangement have not been indicated since there would very likely be more than one catalyst case with intermediate heat exchange for heat removal.

Coker distillate is brought into the reactor section through preheat exchange in or following the reactor section and then through a charge heater. Recycle gas, rich in hydrogen, combines with the heated feed ahead of the reactor section. The reactor effluent, after cooling, enters a high pressure receiver where the recycle gas stream is separated, and from which the liquid is flashed through pressure reduction to a low pressure receiver. Additional gas is released to fuel from the low pressure receiver, and the liquid can be pumped to storage or other processing units. The recycle gas stream picked up from the high pressure receiver with compressors is sent to a Girbitol unit for the removal of H_2S made by the hydrogenation of sulphur compounds in the reactor section. Following the Girbitol unit, a water wash is provided for the recycle gas stream to remove ammonia formed in the reactor section by the hydrogenation of nitrogen compounds. After bleeding off a small stream from the recycle gas stream, to release light hydrocarbons formed by hydrocracking reactions, makeup hydrogen is introduced and the cycle is repeated.

Coker distillates made from either raw tar sand or wet oil using the fluidized solids pilot plant have been prepared by condensing the still or reactor overhead without passing through fractionation equipment of any kind. Solid material in the still effluent, not removed by cyclone separation, therefore appears in the condensate and even though all samples are allowed to settle before analyses are made, some particles, presumably colloidal, remain in suspension. Reference to the proposed flow diagram of a large scale fluidized solids coking unit shows the still overhead entering a fractionator from which a liquid bottoms stream is recycled back to the still to return a continuous stream of solids back to the still. The amount of this stream can be controlled, and is recycled to extinction in the process. Based on fluid catalytic cracking operation, any solid particles carried from the reactor to the main fractionator are concentrated in the bottoms liquid stream, and do not appear in any of the liquid streams withdrawn from the column as side-cuts. Based on this experience, therefore, it is believed that from the standpoint of solids content a satisfactory distillate can be prepared using large scale fluidized solids coking equipment.

The estimates in this survey are developed on the basis of the mineral content being reduced to a practical amount by fractionation. The importance of controlling the mineral content must however, be stressed.

The ash content collected in the pilot plant cyclone separator from the vapor stream on qualitative spectrographic analysis has shown the presence of silicon, as major constituent and traces of vanadium, titanium, magnesium, manganese, nickel and faint traces of lead, chromium, copper, sodium and tin. The chemical analysis of this material is—

Silica (SiO_2)	51.27%
Lime (CaO)	1.04%
Magnesia (MgO)	0.31%
Iron Oxide (Fe_2O_3)	9.16%
Alumina (Al_2O_3)	8.94%
Vanadium (V)	None detected
Water at 110° C. (H_2O)	1.14%
Combustible Matter	23.51%

Mineral Matter in the Coker Distillate

The ash content of the coker distillate hydrogenated in the laboratory decreased from 246 ppm in the charge to 58 ppm in the hydrogenated liquid. A corresponding decrease in the metal content of the oil was observed. A few of these are summarized—

Metals ppm. of Oil	Raw Coker Distillate	Hydrogenated Liquid
Fe	2 - 9	1 - 6
Ni	2 - 9	0.3 - 1
V	8.5 - 35	0.06 - 2
Al	4 - 18	0.4 - 1.6
Mg	5.4 - 21.5	0.01 - 0.06
Ca	4.5 - 19	0.008 - 0.03

Thus, the metals content was reduced by hydrogenation from what would have been dangerously high concentrations, to levels which would make the hydrogenated liquid acceptable as a catalytic cracking feed stock. If raw stock with such an ash content however, were used for hydrogenation there is a potential danger that the reduction in metals content on passing through the reactor section would represent an accumulation of this material on the hydrogenation catalyst. The amounts of these metals disappearing on hydrogenation, and possibly remaining on the catalyst, are such that they might lead to a rapid decline in hydrogenation catalyst activity. At the moment no catalyst life tests have been made.

The approach in this survey, as mentioned previously, to this problem is to prepare a coker distillate by further fractionation which is low in ash and metals content. A vacuum distillation of a sample of coker distillate prepared from raw Bitumount stock produced an 82% overhead containing only 9 ppm. of ash and a lesser quantity of metals than the hydrogenated liquid described above. Therefore, the metallic compounds are concentrated in the heavier fractions of the coker distillate, or are associated at least to some extent, with suspended solids in the total liquid. That there is suspended solid material in the distillate, even after prolonged gravity settling, was demonstrated by examining the supernatent liquid after centrifuging a portion of the above sample of coker distillate. The ash content of the distillate was reduced from 250 ppm to 75 ppm and excepting for Ni and V, the metals content was reduced to values comparable with the 82% vacuum distilled overhead. The results of the vacuum distillation and centrifugation are very briefly summarized below—

	Coker Distillate	Centrifuged Coker Distillate	82% Vacuum Overhead From Coker Distillate
Ash, ppm.	250	75	9
Metals, ppm.			
Fe	1.5 - 6	0.2 - 0.8	0.2 - 1.0
Ni	1.5 - 6	0.7 - 3.0	0.03 - 0.15
V	2.2 - 9	3 - 14	0.05 - 0.2
Al	5 - 20	0.7 - 0.2	0.05 - 0.2
Mg	0.1 - 0.5	0.003 - 0.15	0.01 - 0.04
Ca	1 - 5	0.05 - 0.2	0.05 - 0.2

The very obvious further research which this subject requires will probably lead to material savings in yields and operating costs, and possibly even useful by-product credits. For the present the practice has been adopted in these estimates of fractionating out the bulk of the mineral concentrates and accepting the consequent volumetric losses.

CATALYTIC CRACKING

The hydrogenated desulphurized gas oil is a marketable product as made. It is acceptable to pipe line companies for transportation and after simple fractionation can be utilized by refining companies for blending with other distillate components.

The base oil would also be a very suitable catalytic cracking charging stock. In view of this possible use, the basic properties as affecting catalytic cracking are listed that would be required for evaluation in a refinery development. Under normal circumstances from the 20,000 bbl. per day plant considered in this survey there would be approximately 14,630 bbl. per day of gas oil (after removal of the gasoline) available for catalytic cracking. The capital cost of a 15,000 bbl. plant is estimated to be approximately $5,000,000 within the battery limits.

The properties from the catalytic cracking of the hydrogenated desulphurized distillate have been studied. The total distillates from the hydrogenation plant would be approximately 14% gasoline having an API of 55 and 86% gas oil having an API of 26.5 and 0.27% sulphur by weight. The gas oil only has been charged to the catalytic cracking plant and the following yields have been obtained.

Products	Volume %	A.P.I.	Sulphur Weight %
C_4	5.1		
C_4H_{10}	7.6		
Debut. Gasoline	39.3	54	0.06
Lt. Cycle Oil	28.6	28	0.3
Heavy Cycle Oil	15.8	21	0.4

The estimated octane numbers for the gasoline removed from the desulphurized distillate and for its catalytic gasolines are as follows—

	Catalytic Cracked	Original Distillate
Motor Method, Clear	80	55
Motor Method + 2.5cc* TEL/Gal.	85	74
Res. Method, Clear	92	58
Res. Method + 2.5cc TEL/Gal.	97	75

The light cycle oil would have an I.P.B. of approximately 420 deg. F., 50% point of 520 Deg. F., 90% point of 600 deg. F. and an endpoint of about 650 deg. F. Its cetane number would be low, possibly 35 and its material market would be as a component of heating and burner oils.

The heavy cycle oil which is the next heaviest cut above the light cycle oil would have a distillation range roughly from 550 Deg. F. to 800 Deg. F.

The estimated utilities for a 15,000 barrel per day catalytic cracking plant handling this stock would be—

Steam (150#), lbs. hr.	20,600
Steam (40#), lbs. hr.	16,500
Water, GPM	10,800
Elect. Power, KW	62
Fuel, 10^6 BTU/hr.	20

The above is based on the assumption that all the pumps and the air blower are steam driven, which accounts for the steam requirement of 20,600 lbs. per hour more than is generated from waste heat. On the other hand there is a net production of 16,500 lbs. per hour of low pressure steam above processing requirements. The fuel gas requirement shown is based on the process gas compressors being driven by gas engines. Electric power is used only for instruments and lighting.

The usual running royalty is $0.05 per barrel of feed. The catalyst consumption is assumed to be about 1 lb. per 2 or 3 barrels of feed and the usual operating labor for this type of plant is six including one foreman.

The operating costs will vary with the specific installation but will be in the order of $0.30 per barrel of feed when excluding fuel and overhead.

* Tetraethyl lead

SUMMARY OF CHAPTER II

1. The only areas of bituminous sands that have been adequately tested for mining estimates are those investigated by the Federal Government's drilling program.
2. Overburden removal from the bituminous sands does not present different problems from those previously encountered elsewhere, and there is no evidence that suitable sized equipment cannot excavate and remove it for a cost of not more than $0.17 per cubic yard.
3. The mining to date has all been on a small scale. Large operations of 20,000 cubic yards per day introduce new problems, but at the same time may permit appreciable savings in costs.
4. Open pit mining and a form of block caving without removing the overburden have both been studied.
5. The limited field evidence available on bituminous sand mining is all on the open pit method. Bituminous sand strata loosens on exposure, but for large scale operations it is assumed that drilling and blasting are required.
6. Diamond drilling of small holes with a gel-mud fluid has been the most satisfactory method used to date. The present practice elsewhere in open pit mining is towards using large holes up to 12 inches in diameter for blasting.
7. The indications are that a comparatively small amount of a "slow" powder concentrated in the bottom of the hole would sufficiently disturb the mass for loading.
8. When using large scale equipment it is expected that excavating alone can be done for $0.06 per cubic yard, and hauling for $0.11 over the distances indicated. The total open pit mining cost is estimated as $0.55 per cubic yard including overhead and general administration costs.
9. A block caving method using steam for loosening the bottom of the sands has been investigated and indicates the possibility of attaining total operating costs of $0.38.
10. It appears that field tests on an experimental scale might show the possibility of greatly reducing the cost of recovering the bitumen.
11. The technical principles of hot water separation have been established by the Alberta Research Council and the practical applications have been proven by the Government plant at Bitumount. A 95% bitumen recovery can now be assumed containing 5% mineral matter or less.
12. The non-quartz minerals are the most difficult to separate from bitumen and form a greater proportion of the mineral matter in the end product.
13. The Alberta Government now have a comprehensive development in the Bituminous Sand area. At present it consists of a hot water separation plant (500 barrel per day capacity) distillation unit and the ancillary plant and camp development.
14. For the large scale development a battery of small units (2,000 barrels per day each) has been assumed. Since they are only four times the size of the Bitumount plant they have proven volumetric proportions and also permit close cost estimating.
15. Fluidizing technique is very applicable to bitumen operations.
16. The National Research Council have proven, by the use of a pilot plant, the applicability of the fluidizing principle to the Alberta bitumen. Their tests have produced over 80% distillate, of 16.5 API, containing 4% sulphur. The heat required for the operation has corresponded to the total from the gas and carbon formed. The ability to handle either raw bituminous sand or wet bitumen from the separation plant has been demonstrated.
17. The Oil Industry has proven the efficiency of fluidized technique.
18. The Universal Oil Products Company have applied their experience as developers and designers of the fluidized principle to the specific data from the Research Councils and estimated the pertinent capital and operating costs.
19. The Mines Branch, Ottawa, have developed the principles of cold water separation when using

a diluent oil. Their studies have provided the basic engineering data and balances for design. They have prepared preliminary estimates of the costs of a large commercial plant. Their projects have also investigated the coking and dehydrating of the separated diluted oil.

20. The Mines Branch are investigating the basic properties of the bitumen by the chromatographic analytical approach and have shown the presence of an appreciable amount of sulphur-free cyclic-paraffins. Their present Research projects include hydrogenation investigations on some aspects of the bitumen development.

21. The bitumen contains 5% sulphur. The square mile studied contains 1,500,000 tons of sulphur. The distillate contains 4% which must be reduced before marketing. The processes used recover 60% of the original amount at a cost of about $8.50 per ton starting with hydrogen sulphide. The elemental sulphur recovered (140 tons per day) from a 20,000 barrel per day bitumen plant corresponds to the total Western Canadian sulphur market.

22. The pipe line from the field to Edmonton would cost approximately $5,000,000 and with three pumping stations the tarriff for the distillate would be about $0.28 per barrel.

23. A refinable oil can be recovered from the bitumen by propane extraction. The extract is 52% by weight or 56.6 by volume of the bitumen when the Conradson Carbon is about 2.5%. The gravity (17.3 API) is similar to the fluidizer distillate which is 80% plus of the bitumen.

24. Mild hydrogenation will remove the sulphur (4% to 0.25%) from coker distillate. The hydrogenation plant is estimated to cost $7,000,000 and the operating cost is estimated at about $0.80 per barrel. The hydrogen manufacturing plant is estimated to cost $3,000,000 and the hydrogen production cost is $0.25 per thousand cubic feet.

25. Hydrogenation requires about 1,000 cubic feet of hydrogen per barrel of distillate for the conversion of the sulphur to H_2S and the saturation of the oil. The API of the oil is increased from 16 to 26.

26. Mineral matter present in the distillate is removed by hydrogenation. The minerals require more study. In these estimates they are nearly all removed from the distillate prior to hydrogenation in order to avoid the possibility of serious catalyst loss.

27. The desulphurized coker distillate is a good catalytic cracking charging stock. The yields and costs are given for use where that outlet or method of evaluation is desired.

CHAPTER III

The Cost of Producing Oil from Bitumen and Determination of Its Value

(Evaluation)

The determination of the value of the bituminous sands is, of necessity, a very comprehensive study. It commences with the bituminous sand in place, in a remote district and continues to the delivery of the saleable product from the bitumen in possibly distant markets.

In this Survey Chapter I has dealt with the Raw Material in place. Chapter II has examined the processes, or steps, that are most attractive at present for consideration in forming a sequence, or chain, of operations to produce a marketable product. Chapter III now deals with the actual evaluation.

Chapter III first describes the sequence of operations chosen and defines the products made. The Chapter proceeds with the determination of the market value of that product, and then compiles the costs that will be attracted by the operations involved.

THE SEQUENCE OF OPERATIONS

An accurate evaluation necessitates having a chain of operations from the raw material to the finished product that can be reasonably proven technically and economically. It is only very recently that such an analysis has been possible of fulfillment.

Each step in the sequence selected must have been so developed by tests or commercial useage that—(a) A reasonably proven basis of cost estimates has been established, and (b) The soundness of the process and product quality are known.

COST ESTIMATES
MINING SUMMARY

The Survey has indicated that open cast mining may not be the cheapest. Indeed it appears that a modified form of block caving using steam, may be carried out at some 70% of the cost of open pit mining. Further if some form of extraction of bitumen (even a partial concentration of it) can be applied to the sands in place still larger savings may be possible.

At present, however, open pit mining is the only method in any way proved. It may be taken as reasonably certain that the operations and costs as presented for open pit work could be put into effect. Further there are appreciable savings that may also be found possible with that type of mining after operating experience on a large scale has been gained. For example, the cost of blasting, haulage, and crushing which amount to 22%, 20% and 15% respectively of the total cost of delivering the sands to the plant may be found to be the top costs that will be experienced and that average costs may show a very considerable reduction. The estimated working costs are—

OPEN PIT MINING COST
Sec. 23, Twp. 92, Rge. 10, W-4

	Per Cubic Yard Overburden	Per Cubic Yard Bituminous Sand
Overburden—		
Excavating	$0.05	
Hauling	.12	
Total	$0.17	$0.065
Bituminous Sands—		
Drilling and Blasting		.120
Excavating		.060
Haulage		.110
Crushing and Conveying		.085
Total Direct Cost		$0.440
General Expense (Camp, etc.)		.110
Total Cost Delivered to Plant		$0.550

The operating costs have been so developed that replacement of equipment as worn out is provided for. The initial capital cost of the mining equipment has been estimated as follows—

CAPITAL COSTS OF ORIGINAL EQUIPMENT

Excavating Equipment and Scrapers	$1,200,000.
Drilling Equipment and Service Trucks	80,000.
Haulage Trucks	350,000.
Crushing and Conveying Equipment	300,000.
	$1,930,000.

The selection of the exact sizes of equipment for large scale operations on the site chosen for initial mining would only be made after field drillings and tests had thoroughly checked all the conditions that would be encountered in the overburden removal, response or tendency of the bituminous sands to break for loading on large scale blasting, and the special developments required for winter operation.

The extent to which equipment can be applied to both services, that is, overburden removal, and of bituminous sand mining, will also justify full consideration.

COST ESTIMATES

Hot Water Separation Plant

The equipment costs for this processing step were based on the actual erected cost of $203,160 shown for the separation plant at Bitumount in the Report of the Alberta Government. That plant had proven nominal capacity of 500 tons per day of sand and the reported cost bears its appropriate portion of all overhead charges. The large scale development is based on the use of a battery of 17 units each four times (2,000 tons per day) of the Bitumount plant. This plant scaling relationship predicts an estimated cost of $9,100,000 for the battery of 17 units. Although this figure would be low because the $203,160 cost of the pilot plant was based on 1946-1947 prices it would be compensated by design simplifications and smaller overhead charges for the large plant.

The overall material balances which are shown in tabular form in respect to feed and net products, and the components bitumen, water and solids are based on product stream composition found at the Bitumount plant.

Dehydration of, and Diluent Recovery From Wet Oil From Hot Water Process

Following the introduction of diluent to the wet oil and the settling of the blend, the settler overflow is to be processed to remove the water and diluent in equipment very similar to that used in the field plant. This equipment involves a heater, a flash column, a column overhead receiver and appropriate pumps, condensers and coolers. Heat and material balances were made for the heater, and the flash column and its accessories, assuming that all of the water and diluent would be removed as overhead vapors from the flash column. The flash column bottoms would feed at an estimated temperature of 575 degrees F. directly to the coking unit heater. Although the 155 degrees F. feed to the dehydrator heater might be preheated by exchange with flash column overhead vapors, this was not considered in estimating fuel requirements for the dehydration step.

From costs of crude units having similar heater and column sizes the equipment cost of the dehydration and diluent recovery unit was estimated to be $950,000.

Bitumen Coking

The partial coking of the dry oil from the dehydration step in conventional thermal coking equipment has been studied from the standpoint of estimating equipment costs, yields, utilities and operating labor.

The product yields from this coking are based on the Universal Oil Products Company tests when coking a 7.3 API dry bitumen from Abasand. That bitumen had no appreciable amount of solids and contained 5.3% of sulphur.

The estimated cost of the equipment is based on a revised detailed estimate made for a similar coking unit in 1949 when processing 14,000 barrels per day of feed.

Various types of coking could be considered for this operation. These would include the batch oven type of coking, the conventional chamber type that has been used in this survey and the more recently introduced continuous type. The yields from these three are probably similar and for the purpose of securing representative yields and costs the chamber type process was considered satisfactory.

In regard to the overall application of coking in the processing of the bitumen it is noted that they all produce coke residue as a net product. There is, however, no market outside the actual plant for coke in that area. This is one reason that the principle of coke production has not been applied in these operations.

Cold Water Separation

Material balances, energy requirements and utility requirements for the cold water process have been prepared by the Mines Branch, Ottawa. It should be emphasized that this process has not had the benefit of being applied on a semi-commercial scale and the estimates for a number of the sections that have been developed from the small pilot plant may be capable of being appreciably reduced in cost. The very recent work in the Mines Branch has shown, for example that material savings can be made in items such as the amount of water required.

The rough and preliminary estimates have indicated that the material cost of the plant would be 6 million dollars which amount it has been similarly estimated would be increased to approximately 12 million dollars by the transportation to the area, machinery installation, building erection and associated developments.

The preliminary design of the dehydration and bitumen coking steps following the cold water separation was made in the same manner as that used in the estimates for the hot water process.

Fluidized Processing of Raw Bituminous Sand

The estimates of the direct processing of bituminous sand in a fluidizing unit are based entirely on the results from the pilot plant operated by the National Research Council.

Heat and weight balances have been prepared for a still temperature of 950 degrees F. and a burner temperature of 1,300 degrees F. in order to arrive at fuel requirements, equipment sizes, solids circulation rates etc. In these process calculations, reject sand was taken from the burner and cooled to 600 degrees F. in steam generators before discarding. In order that the process would support itself from a thermal standpoint all of the light hydrocarbon gas would need to be burned in addition to the coke.

In the preliminary design of equipment for processing 20,000 cubic yards per day of raw sand the required sizes of some of the principal vessels, the waste heat boiler and the air blower were larger than those in existing fluid catalytic cracking units. This situation would possibly lead to the use of multiple units. Excepting for the appropriate equipment for introducing the raw tar sand into the coking unit, eliminating extraneous lumps, rocks, etc., and disposing of reject sand, it is visualized that most of the major components of the coking unit would resemble those in a conventional fluid catalytic cracking unit.

Any plant cost figures which might be assigned to figures of this kind at this time would only be very approximate. If the plant design resembled conventional catalytic cracking equipment in structural arrangement and materials of construction, it appears that the cost per barrel of bitumen being processed would be in the order of 4 times the cost of a similar size catalytic cracking plant. At the same time, however, it would be necessary to provide other very extensive plant developments which would include—

(a) apparatus for feeding the bituminous sand to the still in a sufficiently fine state.

(b) provisions for transporting the hot rejected sand away from the plant.

(c) materials of construction capable of withstanding the erosive properties of the sand at high

temperature, and means of collecting and withdrawing the lumps and large pieces of solid matter.

The above points will indicate that the developing of an accurate total cost is not possible at present. It is desired to emphasize, however, that this does not necessarily mean that some application of the process cannot be applied later directly to the bituminous sand. There is, however, no parallel at present in industry which permits an assurance of the operation on a large scale or of the limits to the costs that would be encountered.

Fluidized Processing of Wet Bitumen From the Hot Water Separation Plant

This study is based on the continuous processing of wet bitumen in the fluidized solids plant to accomplish—(a) dehydration, (b) solids removal from the oil, (c) thermal coking of the bitumen, all in one operation.

Recent work at the National Research Council has proven the feasibility of the process. Continuous operation has been secured and the plant yields determined.

Heat balances prepared for this type of processing indicate combustion of the coke formed in the still provides just enough heat under average circumstances to support the processing unit.

Vessel sizes and other items for this unit are comparable with those for a fluid catalytic cracking unit completed at the end of 1949. Based on these comparisons and a consideration of more costly materials of construction for this unit when handling sand, the cost of the plant to process 34,000 barrels per day of bitumen and water has been estimated as $10,500,000.

The material balances and utility requirements have been prepared in the light of the pilot plant results and the experience of commercial fluid catalytic cracking plants of similar size.

SEQUENCE OF OPERATIONS SELECTED

The sequence of operations select themselves for evaluation after thorough analysis of costing and operating experience of the different alternatives, for present estimating. The sequence is—

1. Open pit mining
2. Hot water separation
3. Fluidized plant distillation of wet bitumen from the hot water process
4. Desulphurization of the distillate from fluidized coking by mild hydrogenation.
5. Disposal in a major market of the desulphurized distillate with evaluation as such or from its potential break up on catalytic cracking.

Production

The product produced by a large scale development for marketing should comply with the following basic conditions—

1. It should be suitable for transport by pipe line to a market directly, or to an intermediate point for any further treating required.
2. It should be of a quality that would permit it to be placed directly on a large competitive market or be capable of being refined by conventional methods so that its products would be acceptable to such a market.
3. When complying with 1 and 2 above it should represent as economic a production cost as possible and the efficiency of its full scale production should not be dependent on by-product or local market credits that could readily reach saturation.

There is also possible production that might be used on local markets such as asphalt or output such as raw coker distillate that would comply with some, but not with all of the foregoing conditions. Some such production although unsuitable as the basis for a large industry might usefully supplement it.

Mention will be made of the possibilities of use in the non-fuel markets.

BITUMEN MARKETS OTHER THAN AS FUEL

The development and utilization of the bituminous sands on a large scale at present necessitates their major use being as different forms of liquid fuel. It is desirable, however, to consider also some other relatively large oil markets as a possible outlet for the bitumen.

The following are particularly mentioned—

(a) The possible use of bitumen or bituminous sand for road paving.

(b) The possible production of carbon black.

(c) The possible gassification of the bitumen.

Road Materials

1. **Bituminous Sands for Paving**[36]—The making of asphalt pavements is possibly the first outlet normally considered for the use of bituminous sands. In the early attempts to utilize bituminous sands, trial asphaltic pavements were laid using this material. One was built in Edmonton over thirty years ago during the earliest studies of the formation. It is still in use and in relatively good order. Pavement was also laid at a later date at Jasper, which is also bearing proof of the ability of this material to be used successfully in a road paving aggregate.

   Two basic conditions have mitigated against road surfacing forming an appreciable outlet for bituminous sands. One has been the cost of shipping the mineral matter over the long distances which are inevitable to reach a market, and the other has been the availability of relatively cheap asphaltic oils produced from normal crude oil. When it is appreciated that this deposit lies about 300 miles North of the closest market in the Province, and it is also appreciated that suitable sand for paving purposes can usually be found practically adjacent to the development, the handicap of transportation costs faced by the bituminous sands shipping project is immediately apparent.

   It should also be mentioned that bituminous sands as mined cannot be used as a ready-mixed paving aggregate. It cannot be laid as received, as the case with deposits such as the Kentucky rock asphalt.

   The Alberta material requires adjustment in each of its physical properties to bring it in line with the required specifications. There is too much asphalt and the asphalt is too soft, and also the sand is too fine in texture. These points necessitate bituminous sands as received being corrected by the addition of other mineral aggregate, and the whole mixture being heated to harden the asphalt. Consequently, bituminous sands will only be used economically for paving purposes in areas close to the deposit.

2. **Asphaltic Road Oils from Bituminous Sands.**[37]—A considerable amount of work has been done on the possibility of making asphaltic road oils from bituminous sands. This plan eliminates a good deal of the uneconomical transportation encountered in the use of the unaltered material. The oil could be separated from the sand in the North and shipped to the market. The factors which limit this utilization of the bitumen at present apart from the fact that suitable asphalts for paving purposes from normal crude oils in the Province are available at low cost, are that the unaltered bitumen does not conform to standard road oil requirements. Bituminous sand oil itself is a slow curing oil and when used for road purposes is limited to the slow curing market. The manufacturer utilizing this bitumen in an enterprise that was directed to the production of a comprehensive supply of road oils would also have to use oils from other sources in order to have a balanced production. The crude bitumen is also severely handicapped with transportation costs as it must be moved by rail at present which makes the final cost in any industrial area much more than that of locally produced road oils that have been transported to a local refinery by pipe line. As industry developes in the North there may be a local road oil market that it can secure. It is also to be expected that small developments will ultimately be justified for the whole bitumen in the production of specialty products such as roofing and painting materials.

Carbon Black

The carbon black industry utilizes two main types of material. These are channel black, normally made from natural gas, and furnace black, in the manufacture of which suitable oils can be used as enriching material. The total Canadian market now amounts to about 50 million pounds per year of which about one-half might be channel black and the other half a variety of grades of furnace carbons. The furnace black production will depend on the quality demanded by the market, but its production according to the quality required will vary between about 3.0 and 4.5 pounds per gallon of oil used. The most commonly used oil is an aromatic distillate similar to No. 2 fuel oil in consistency. It may be that an outlet for some aromatic oil production originating from the bitumen can ultimately be found in this way in the carbon black industry. It will be seen, however, that the total oil requirements for the present Canadian market for furnace carbons could be satisfied by a production of a few thousand barrels per day which, although an attractive market, could not be a major influence in such a development.

Gassification of the Bitumen

The suggestion has been made from time to time that the gassification of the bitumen might be a practical method of using it. The reason for the suggestion has probably been that in that way an economically transportable fuel could be made and also when put into a gaseous state the removal of the sulphur would be greatly simplified. This possibility has been considered but it is not practical. If gassification were done by thermal decomposition at a temperature of about 900 degrees F. to the point where coke and gas only were made, it is estimated that there would be about 3,000 cubic feet of gas at 60 degrees F. and atmospheric pressure, and 180 lbs. of coke per barrel of bitumen. If the operation were carried out at a higher temperature, the amount of gas formation would be higher, but its heat of combustion (about 1200 BTU per cubic foot) would be lower, so that the total heating value of the gas would be about the same when expressed as BTU per barrel of charging stock. As the value of the gas from a barrel of bitumen would be in the order of twenty-five cents it is seen to be impractical.

PRIMARY PRODUCTS

By Primary Products, is meant the first bulk untreated oil recovered from the bitumen. The oils vary in nature to some extent with the source of the bitumen from which they are produced as described in the fluidizing distillate results given in Chapter II. When considering the bitumen from only one location, however, there are major variations in both quantity and quality dependent on the method of production that is used.

The possible methods of oil recovery from the bitumen at present are, Vacuum Distillation, Conventional Distillation and Cracking, Conventional Coking, Solvent Extraction, and Fluidized Coking Distillation.

Extraction

The extraction tests for commercial operation have been limited to the use of propane, which is the most commonly used solvent commercially for the processing of heavy asphaltic oils. The product obtained was 56.6% of the volume of the bitumen. It has an API of 17.3, 3.15% sulphur, 2.53 Conradson Carbon and a characterization factor of 11.4. The asphaltic residue (over 40%) would be of no commercial value in that area other than to the extent that it could be used around the plants there as a low grade fuel. In view of the light oil yield being some thirty percent less than that secured by fluidized operation and the quality of the products not being particularly better, this approach has not been continued. Before leaving the possible use of solvents for the recovery of a commercial oil however, it should be noted that the use of special solvents if directed to the recovery of specific components of the bitumen, such as those that are now proved to be present by the chromatographic analytical approach, may prove to be successful. Further if a method of applying solvents and washes to the material in situ can be developed then the solvent-extracted oil might become much more competitive.

Distillation and Coking

The different forms of distillation and coking which involve the use of conventional tube stills all have a major processing problem for the handling as charging stock of wet bitumen containing

an appreciable amount of mineral matter. The presence of the water and sand in the bitumen are not a correspondingly serious handicap to operations with the fluidizing process. The yields and quality of distillate obtained by the older forms of distillation have no particular advantage over the fluidized distillate. The most efficient means of limiting heavy minerals in the distillate requires to be developed further, but it is to be assumed that if this is done by fractionation and recirculation the methods used will be applicable to either process. It is of interest to note that the presence of water in the bitumen with fluidizing process is an advantage from a thermal point of view.

The properties of the distillate made by the fluidizing operation are therefore considered to be the most applicable for consideration as the primary product from the bitumen. Table 13 gives the chemical and physical properties of coker distillates from different sources.

The distillate when in a raw state has only attracted about 50% of the processing costs that it has when desulphurized. It could be used directly where the market requirement tolerated the high percentage of sulphur, or if processed in conjunction with low sulphur oils it could be used to supply a normal market.

Table 13

LABORATORY INSPECTIONS OF DISTILLATES PRODUCED BY COKING BITUMINOUS SAND BITUMEN

	CONVENTIONAL COKING		FLUIDIZED SOLIDS COKING Total Distillate						Desulphurized Blend of Abasand and Bitumount Distillates	
Properties	Debut. Gasoline	Coker Distillate	Abasand		Bitumount		M.-R. Lakes			
A.P.I. at 60° F.	51.9	16.6	15.5		16.6		14.1		26.2	
Sp. Gr. at 60° F.	0.7715	0.9554	0.9626		0.9554		0.9718		0.8973	
Total Sulphur wt. %	1.86	4.04	4.12		4.01		3.83		0.26	
Mercaptan Sulphur wt. %	0.226									
Nitrogen wt. %			0.27		0.22		0.27			
Con. Carbon Resid. wt. %			7.9		5.7		7.85		1.22	
B.S. & W. vol. %		0.1	0.05		0.15		1.5			
Tar Acids vol. %		0.2	0.8		2.1					
Tar Bases vol. %		0.1	0.35		0.6					
Bromine No.	80	47	54		45		49		10	
Olephin Content wt. %	55						89			
Aromatic Content wt. %	12									
Pour Point Deg. F.		20	30		30		25		35	
Viscosities— Saybolt Univ. Secs. at 210° F.									34.2	
Secs. at 100° F.		70.8	200		173		321		55.3	
Kinematic, Centistokes at 210° F.										
at 100° F.		13.32	43.17		37.15		69.37		2.377	
at 32° F. (Est.)		90	540		430				8.984	
Octane Numbers— F-2, Clear (Unisol Sweet)	69.1									
F-2, 2.5cc TEL/Gal.	74.0									
Ash Content p.p.m.			176		315		660		58	
Distillation	Atmos.	Atmos.	Atmos.	Vac.	Atmos.	Vac.	Atmos.	Vac.	Atmos.	Vac.
I.B.P. Deg. F.	126	443	185	122(a)	224	100(a)	181	98(a)	200	108(a)
5%	165	466	285	246(a)	365	321(a)	362	312(a)	294	250
10%	186	486	400	375(a)	450	421(a)	500	462(a)	364	330(a)
30%	232	550	617	662	610	651	633	702	537	580
50%	275	621	658	776	668	776	679	806	634	681
70%	315	690	694	886	703	877	705	909	720	751
90%	358	715	720	960(b)		956(b)	726	972(b)	760	857
E.P. Deg. F.	400	760								
% Recovered	98.5	97.5	90.5	82.0	92.5	83.0	91.0	86.5	98.5	97.5
% Bottoms	1.0			18.0		17.0		13.5		2.5
Wt. % Coke		2.5	9.3		7.5		9.0		1.3	
% at 400° F. by Hempel				11.3		8.6		7.0		15.0

(a) Atmospheric Hempel (b) 80% Point

This high sulphur raw gas oil, although valuable in some refinery programs is not a sufficiently finished product to secure a wide established market. Its quality and production costs are, however, sufficiently described in the survey to permit its evaluation for any specific use.

VALUE OF PRODUCTS OBTAINABLE BY FURTHER REFINING OF DESULPHURIZED COKER DISTILLATE

Evaluation by refinery processing

The desulphurized coker distillate might be processed in a variety of ways in a refinery, such as by thermal and catalytic cracking, or its fractionated components might be used directly by blending into marketable products. One approach to calculating the value of the desulphurized distillate is to place a known value on conventional marketable products obtainable by processing the oil by a refining step whose operating costs are well defined.

This involves selecting a location for the evaluation in order to have corresponding values for the products and operating costs. When considering a product of this kind that is not being evaluated in conjunction with any existing operations, the location chosen for evaluation should represent a major market that will not be affected appreciably by the advent of the material under consideration. The Chicago market has been considered particularly suitable for this purpose. It represents a big market with alternative major sources of supply, on which this oil could be placed at known costs.

The application of the method including yields, operating costs and product prices are shown for catalytic cracking of 15,000 barrels per day of desulphurized oil at the present time in the Chicago area. The coker distillate contains about 12% gasoline which would be removed so only gas oil remains to be processed by the cracking unit, with credit being given to the removed gasoline in the products.

EVALUATION OF THE DESULPHURIZED COKER DISTILLATE
BY CATALYTIC CRACKING OF THE GAS OIL (88%) PORTION

CREDITS—	Unit Value \$/Bbl.	Product Bbls./Bbl. Coker Distillate	Value \$/Bbl. Coker Distillate
Fuel Gas	15¢/1000 (Cu. Ft.)	260 (Cu. Ft./Bbl.)	0.039
Butane - Butylene	4.20	0.112	0.460
Catalytic Gasoline	5.25	0.346	1.818
Gasoline in Coker Dist.	4.85	0.120	0.582
Light Cycle Oil (No. 3)	4.20	0.252	0.106
Heavy Cycle Oil (No. 5)	3.20	0.138	0.441
TEL Savings (a)			0.138
TOTAL CREDITS			4.586
DEBITS—			
Direct Operating Costs			0.300
Refinery Overhead, Depreciation, Taxes, Insurance, etc.			0.254
TOTAL DEBITS			0.554
ESTIMATED VALUE OF DISTILLATE DELIVERED TO REFINERY IN CHICAGO AREA			4.032

(a) When 91 clear F-1 octane number catalytic gasoline is blended in with lower octane gasolines to make an 83 octane House-brand marketable grade, it has an estimated value of \$0.40 per barrel in terms of TEL.

STUDY OF VALUE OF DESULPHURIZED GAS OIL FOR DIRECT SALE

The quality of the oil is shown in the accompanying tabulation. The quality is that which was found when securing maximum yields in the fluidizing plant and at the same time keeping within reasonable operating conditions. The maximum yield is attained with the lowest operating temperatures permissible while avoiding the extremely low temperatures that create unworkable processing conditions. It will thus be seen that no attempt has been made in the initial operation of fluidized distil-

lation and desulphurization to produce a tailor-made market product in respect to any of the physical properties such as volatility and viscosity.

The final product consists of 88% gas oil and 12% gasoline. The gasoline can be evaluated separately and directly. The gas oil although not designed for it, is very similar to No. 2 Fuel. The gravity, viscosity, flash point and water and sediment could correspond to the requirements. The pour point at less than minus 30 as compared to a requirement of 0 to plus 20 is much better than required and similarly the sulphur at 0.25% is appreciably better than the standard products of say 0.5% to a maximum of 1%. On the other hand the Conradson Carbon value and the volatility are both appreciably worse than the specification requirements. The Conradson Carbon could probably be improved. The volatility, however, will probably not be easily changed without a loss in volume.

The relationship of No. 2 Fuels to the corresponding crude oil prices has been studied for the production from the Illinois Basin, the Mid-Continent and the Texas crudes, for the years 1933 to 1950 inclusive. The results are shown in column graphs number 21, 22 and 23. The graphs have been developed from the monthly averages for each year. It will be seen that No. 2 furnace oil is constantly above the price of the corresponding crude. In the case of the West Texas and the Illinois production the average price has been 40% above that of crude, while in the case of the Mid-Continent it averages approximately 30% above the crude price over the years shown. Although the percentages mentioned are indicative of the relationship between crude and No. 2 furnace oil prices, the exact relationship for any given case is dependent on such factors as quality of the crude in question, its location, and the nature of the gas oil market. The crudes and gas oils used in these assumptions are, however, based on comprehensive reviews of the crudes and gas oils that are considered to be both representative and comparable for this purpose. It will also be appreciated that as further constant charges, such as pipe line costs, are added to both crude and products that the percentage differential will correspondingly decrease.

Briefly, the price history for the crudes shown indicate that a good quality of No. 2 furnace oil can be expected to sell for about one-third more than similar crudes. In this connection, however, it is noted that the normal quality of No. 2 furnace oil sold is appreciably above the API specification for that product. Thus before a desulphurized coker distillate is evaluated as No. 2 furnace oil it must be established that each property, such as the volatility previously mentioned, that does not at present conform to the market specification will satisfy the requirements.

The price of Canadian crude oils are now being established at the Head of the Lakes following the completion of the pipe line from Alberta. On the assumption that Redwater 30 API crude is priced at $3.00 at the Eastern end of the pipe line, it is to be assumed that the desulphurized

Table No. 14

TABLE SHOWING THE PRICE PERCENTAGE THAT NO. 2 AND BUNKER FUELS ARE OF GASOLINE

(All Prices Have Been Adjusted to Gasoline at 10 Cents/Gallon)

	GASOLINE AT 10c GAL.	NO. 2 FUEL CENTS/GAL.				NO. 6 FUEL BUNKER CENTS/GAL.			
		Gulf Coast	Mid-Continent	North Texas	Philadelphia	Gulf Coast	Mid-Continent	North Texas	Philadelphia
	$	$	$	$	$	$	$	$	$
1927	.1000					.0394		.0365	
1928	.1000					.0217		.0195	
1929	.1000		.0410			.0208	.0190	.0196	
1930	.1000		.0476			.0231	.0179	.0192	
1931	.1000		.0492			.0280	.0186	.0191	
1932	.1000		.0509		.0626	.0215	.0121	.0205	
1933	.1000	.0700	.0634		.0720	.0321	.0188	.0279	
1934	.1000	.0690	.0608		.0763	.0398	.0247	.0350	.0472
1935	.1000	.0605	.0565		.0676	.0334	.0225	.0307	.0409
1936	.1000	.0567	.0534		.0633	.0332	.0236	.0265	.0371
1937	.1000	.0668	.0633		.0679	.0349	.0310	.0319	.0412
1938	.1000	.0661	.0725		.0688	.0308	.0224		.0375
1939	.1000	.0639	.0681		.0683	.0348	.0204		.0391
1940	.1000	.0771	.0712		.0733	.0434	.0257		.0419
1941	.1000	.0630	.0625		.0665	.0365	.0324		.0428
1942	.1000	.0667	.0614		.0664	.0350	.0335		.0409
1943	.1000	.0652	.0609		.0725	.0426	.0319		.0469
1944	.1000	.0658	.0610		.0732	.0426	.0348	.0385	.0473
1945	.1000	.0663	.0616		.0712	.0408	.0392	.0387	.0461
1946	.1000	.0752	.0685	.0740	.0751	.0489	.0437	.0448	.0532

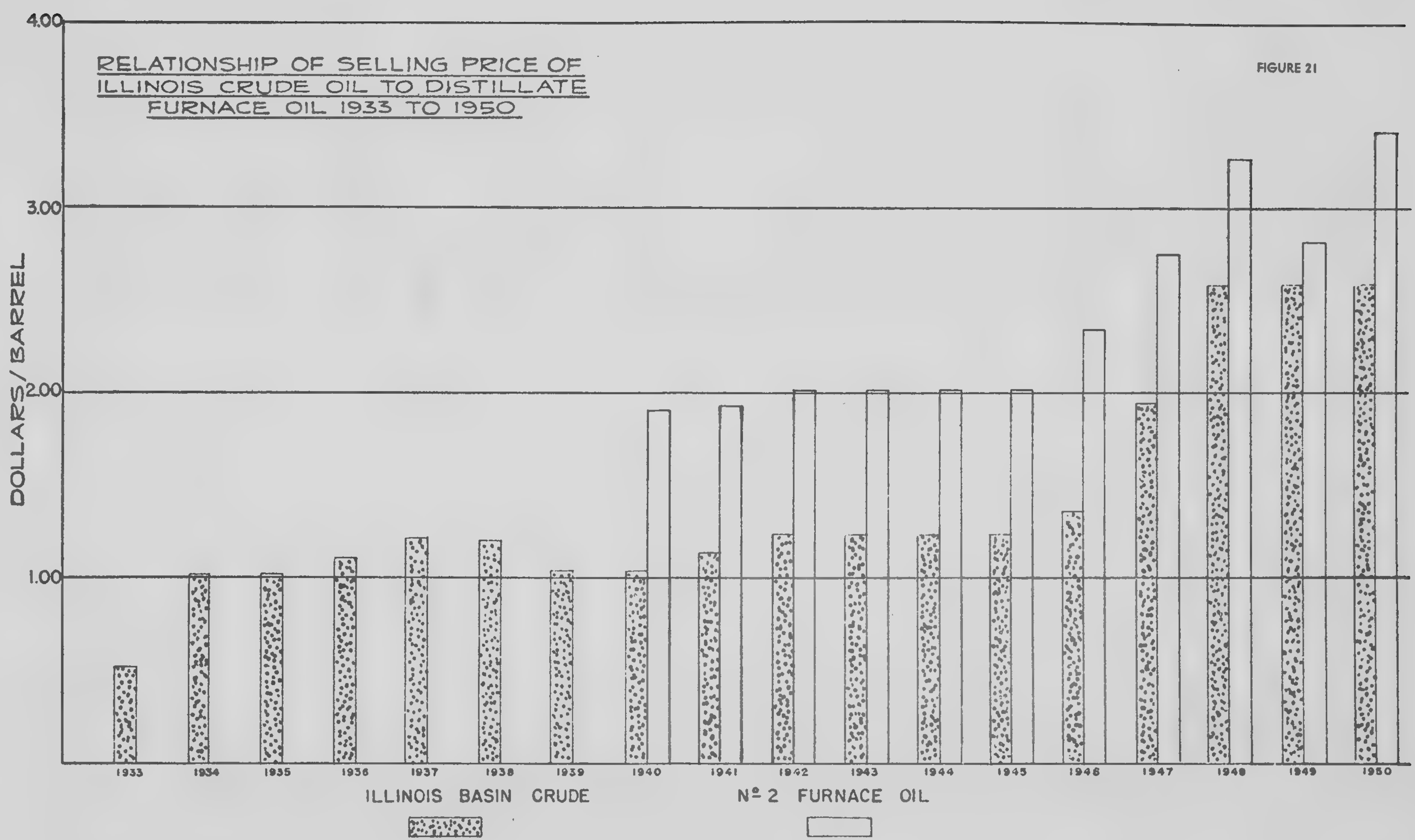
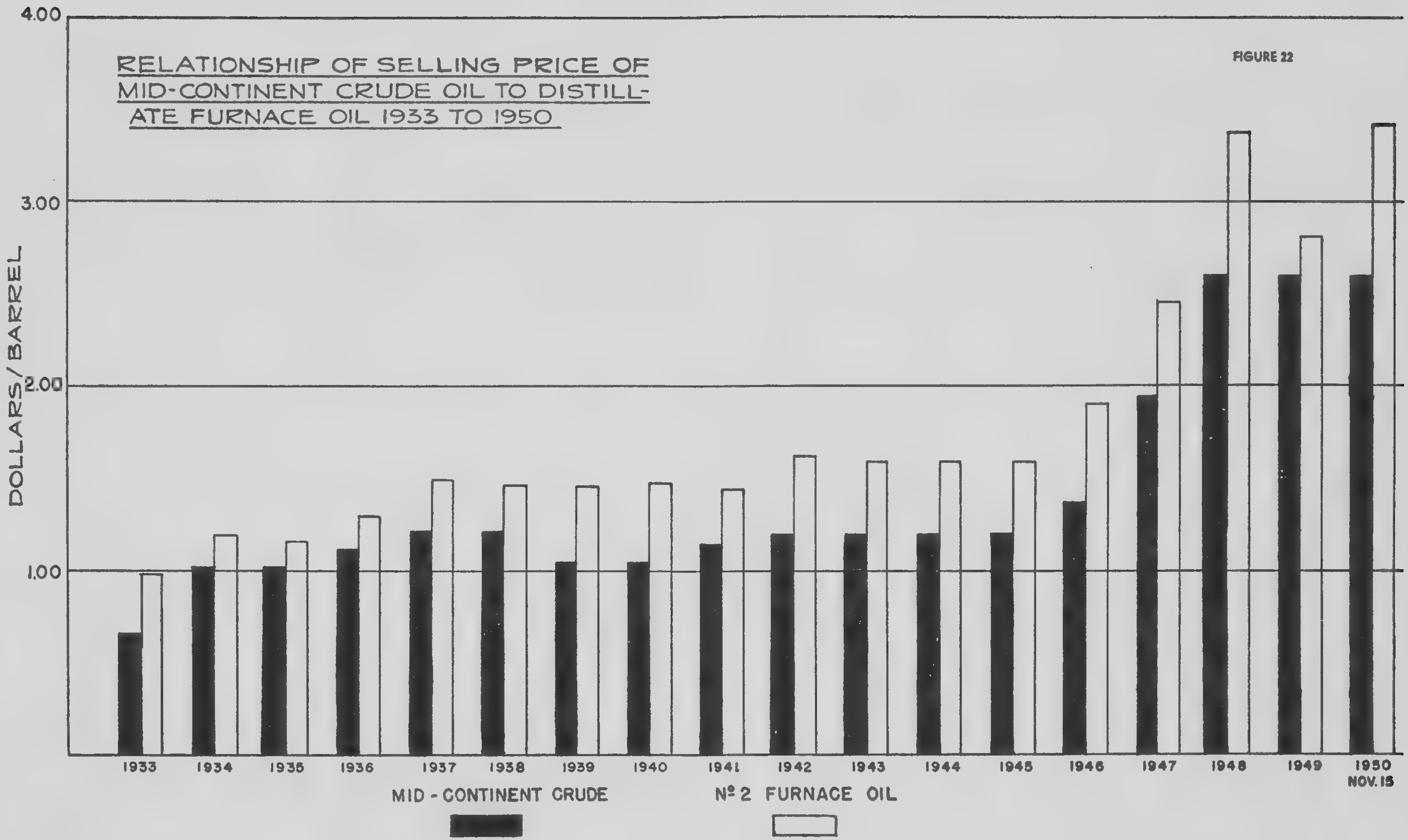
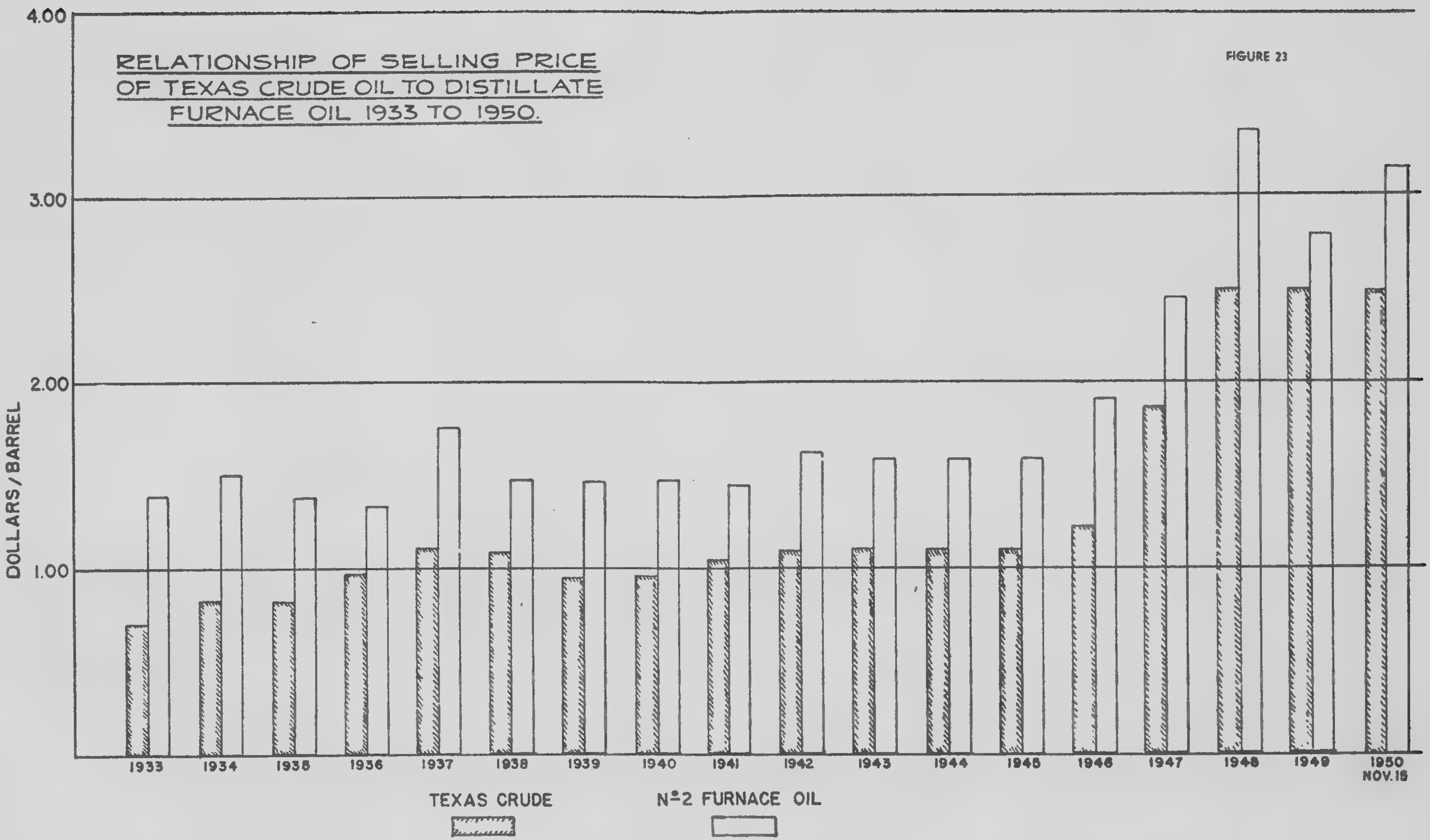

RELATIONSHIP OF SELLING PRICE OF ILLINOIS CRUDE OIL TO DISTILLATE FURNACE OIL 1933 TO 1950
FIGURE 21
4.00
3.00
2.00
1.00
DOLLARS/ BARREL
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
ILLINOIS BASIN CRUDE
Nº 2 FURNACE OIL

FIGURE 22



RELATIONSHIP OF SELLING PRICE OF MID-CONTINENT CRUDE OIL TO DISTILLATE FURNACE OIL 1933 TO 1950
DOLLARS/BARREL
4.00
3.00
2.00
1.00
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950 NOV. 15
MID - CONTINENT CRUDE
Nº 2 FURNACE OIL

FIGURE 23


RELATIONSHIP OF SELLING PRICE
OF TEXAS CRUDE OIL TO DISTILLATE
FURNACE OIL 1933 TO 1950.
4.00
3.00
2.00
1.00
DOLLARS / BARREL
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
NOV. 15
TEXAS CRUDE
Nº2 FURNACE OIL

coker distillate would realize at least $3.50 making an allowance for expenses incurred in adjusting the quality.

In conclusion the evaluation of the distillate by catalytic cracking at Chicago has been shown as $4.032 (U.S.). This value if adjusted to a price at the end of the Canadian Pipe Line by making allowances for freight, duty and currency, confirms the value of $3.50 for the desulphurized distillate mentioned previously when delivered to storage at the Head of the Lakes.

Another approach to the evaluation of the No. 2 furnace oil that may be mentioned is that of relating it to the price of gasoline. Table 14 shows the relationship in major U.S. markets. Its application in this case indicates that the order of value mentioned for the gas oil is justified.

REFINERY PROCESSING COST SUMMARY

The estimated capital costs for various processing units in the refining plant which have been discussed earlier in this Chapter appear summarized in Table 15, and the sequence of operations considered to be most attractive has been listed.

Overall material balances for each of the steps in the selected processing sequence are presented in Table 16 for hot water separation, Table 17 for the fluidized coking of the wet oil from the hot water process, and in Table 18 for the desulphurization of the fluidized coker distillate.

Material balances for three alternate processing sequences to produce a coker distillate are also presented. Table 19 shows this balance for cold water separation followed by dehydration and conventional thermal coking of the dry oil. Table 16 includes a material balance for the hot water separation process followed by dehydration and conventional thermal coking of the dry oil, while Table 20 presents a material balance for the fluidized solids coking and distillation of unaltered bituminous sand.

An outline of estimated processing costs, both direct and indirect, for the production of a coker distillate from raw bituminous sand is presented in Table 21 for three alternate processing sequences. The final processing cost for each of these sequences can be summarized as follows—

	$/Bbl. Coker Distillate
1. Hot water separation and fluidized coking of wet oil	0.726
2. Hot water separation, dehydration and conventional coking:	
(a) Using diluent	0.948
(b) Without diluent	0.787
3. Cold water separation, dehydration and conventional coking	1.382

Table 15

CAPITAL COSTS OF REFINING UNITS

Refining Unit	Erected Cost Dollars	
1. Hot Water Separation Plant	$9,100,000.00	
2. Conventional Tube Still Dehydration for 1.	950,000.00	
3. Conventional Thermal Coking for 1.	5,900,000.00	
4. Cold Water Separation	15,000,000.00	(A)
5. Conventional Tube Still Dehydration for 4.	1,600,000.00	
6. Conventional Thermal Coking for 4.	6,750,000.00	
7. Fluidized Coking of Wet Oil from 1.	10,500,000.00	
8. Fluidized Coking of Unaltered Bituminous Sand		(B)
9. Hydrogen Manufacture	3,000,000.00	
10. Hydrogenation (Sulphur Removal) of Distillate from 7.	7,000,000.00	

(A) No semi-commercial plant built. Above globular figure probably capable of material reduction.

(B) Since this plant does not correspond to any commercial units for which accurate cost determinations have been made, it would be a major undertaking to determine a realistic cost. The general estimates made, however, indicate that the cost without the pulverizing section and the hot sand removal plant would be in the order of twice No. 7.

Table No. 16

MATERIAL BALANCE FOR THE SEQUENCE
HOT WATER SEPARATION, DEHYDRATION AND CONVENTIONAL COKING

HOT WATER SEPARATION			DEHYDRATION AND DILUENT RECOVERY			BITUMEN COKING			
Feed to Processing Unit									
Tar Sand	Lbs./Hr.	B/D	Wet Oil	Lbs./Hr.	B/D	Dry Oil	Lbs./Hr.	B/D	API
Sand	2,388,500		Bitumen	358,800	24,100	Bitumen	324,800	21,600	7.5
Bitumen	393,400	26,400	Water	130,000	8,930	Clay	13,300	390	
Water	28,100		Clay	36,400	1,060				
Steam to Hoppers	33,700		Diluent	107,800	8,430				
Make-up Water	1,057,480								
Fluidizing Water	2,500,000								
	6,401,180			633,000	42,520		338,100	22,190	
Products from Processing Unit									
Waste and Sand Tailings	Lbs./Hr.	B/D	Waste	Lbs./Hr.	B/D	Distillate	Lbs./Hr.	B/D	API
Bitumen	34,600	2,300	Oil	48,500	3,430	C_4	2,900	350	
Water	3,489,280		Water	28,500		Gasoline	51,000	4,530	51.9
Sand	2,352,100		Clay	23,100		Gas, Oil	177,000	12,700	16.6
Wet Oil			**Dry Oil**			**Coke (a)**			
Bitumen	358,800	24,100	Bitumen	324,800	21,800	Coke	68,300		
Water	130,000		Clay	13,300	390	Clay	13,300		
Clay	36,400		Recov. Diluent	93,300	7,300				
			Water	101,500		Gas	25,600 (b)		
	6,401,180			633,000			338,100	17,580	

(a) Heating value about 12,500 BTU/lb.

(b) 590,000 SCFH or 530 x 10^6 BTU/hr. Heating value.

Table No. 17

MATERIAL BALANCE FOR
FLUIDIZED COKING OF WET OIL FROM
HOT WATER SEPARATION PROCESS

Feed to Processing Unit	Lbs./Hr.	B/D	A.P.I.
Wet Oil			
Bitumen	358,800	24,100	7.5
Water	130,000	8,930	
Clay	36,400	1,060	
	525,200	34,090	
Products From Processing Unit			
C_4 and Lighter Gas(a)	36,590		
Debutanized Distillate			
Gasoline	20,450	1,820	52
Gas Oil	245,060	17,660	17.1
Coke (b)	56,700		
Water	130,000		
Reject Clay	36,400		
	525,200		

(a) 515,000 SCFH or 700 x 10^6 BTU/Hr. Heating Valve.
(b) Burned in process.

Table No. 18

MATERIAL BALANCE FOR HYDROGENATION
(SULPHUR REMOVAL) OF FLUIDIZED COKER DISTILLATE

Feed to Processing Unit	Lbs./Hr.	B/D	A.P.I.
Debutanized Coker Distillate	265,510	19,480	19.8
Hydrogen Consumed(a)	4,280		
	269,790		
Products From Processing Unit			
H_2S	10,860		
C_4 and Lighter Gas(b)	5,390		
Hydrogenated Liquid	253,000	19,800	30.0
	269,790		

(a) Net consumption in hydrogenation reactions. Does not include small amount lost in process gas bled from recycle stream.
(b) Does not include hydrogen bled from process with this stream.

Table No. 20

MATERIAL BALANCE
FOR THE FLUIDIZED COKING DISTILLATION
OF
UNALTERED BITUMINOUS SAND

Feed to Processing Unit			
Tar Sand	Lbs./Hr.	B/D	A.P.I.
Sand	2,388,500		
Bitumen	393,400	26,400	7.5
Water	28,100		
Steam to Hoppers	33,700		
	2,843,700		
Products from Processing Unit			
Distillate	Lbs./Hr.	B/D	A.P.I.
C_4	2,090	255	
Gasoline	18,800	1,675	52
Gas Oil	290,300	20,700	15.8
Coke (a)	50,100		
Reject Sand	2,388,500		
Water	61,800		
Gas (a)	32,110(b)		
	2,843,700	22,630	

(a) Burned in Process.
(b) 465,000 SCFH or 650 x 10^6 BTU/Hr. Heating Valve.

Table No. 19

MATERIAL BALANCE OF THE SEQUENCE
COLD WATER SEPARATION, DEHYDRATION AND CONVENTIONAL COKING

COLD WATER SEPARATION			DEHYDRATION AND DILUENT RECOVERY			BITUMEN COKING			
Feed to Processing Unit									
Tar Sand	Lbs./Hr.	B/D	Wet Oil	Lbs./Hr.	B/D	Dry Oil	Lbs./Hr.	B/D	API
Sand	2,388,500	26,400	Bitumen	382,600	25,670	Bitumen	382,600	25,670	7.5
Bitumen	393,400		Diluent	382,600	29,950	Clay	24,600	716	
Water	28,100		Water	244,100	16,800				
			Clay	24,600	716				
Diluent	393,400	30,800							
Process Water	14,726,000								
	17,929,400			1,033,900	73,136		407,200	26,386	
Product From Processing Unit									
Waste and Sand Tailings	Lbs./Hr.	B/D	Dry Oil	Lbs./Hr.	B/D	Distillate	Lbs./Hr.	B/D	API
Bitumen	10,800	730	Bitumen	382,600	25,670	C_4	3,450	420	
Diluent	10,800	850	Clay	24,600	716	Gasoline	60,200	5,340	51.9
Sand	2,363,900					Gas Oil	208,350	14,920	16.6
Water	14,510,000		Recover. Diluent	382,600	29,950				
Wet Oil						Coke (a)			
Bitumen	382,600	25,670	Water	244,100		Coke	80,400		
Diluent	382,600	29,950				Clay	24,600		
Clay	24,600					Gas	30,200(b)		
Water	244,100								
	17,929,400			1,033,900			407,200	20,680	

(a) Heating value about 11,500 BTU/lb.

(b) 696,000 SCFH or 626 x 10^6 BTU/Hr. Heating value.

Table No. 21

COSTS OF RECOVERY AND REFINING TO PRODUCE A COKER DISTILLATE

		Hot Water Separation, Dehydration and Conventional Coking Plant Cost—$15,950,000 Coker Dist. Yield—17,580 B/D			Cold Water Separation, Dehydration and Conventional Coking Plant Cost—$23,350,000 Coker Dist. Yield—20,680 B/D			Hot Water Separation and Fluidized Coking of Wet Oil Plant Cost—$19,600,000 Coker Dist. Yield—19,480 B/D		
	Unit Costs	No. of Units	Cost $/Day	Cost $/Bbl.	No. of Units	Cost $/Day	Cost $/Bbl.	No. of Units	Cost $/Day	Cost $/Bbl.
1. Overhead and General Administration			703	0.040		828	0.04		780	0.040
2. Depreciation, Maintenance, Taxes and **Insurance on** Processing Units:										
(a) Depreciation at 10% Plant Cost per year			4,370			6,397			5,370	
(b) Maintenance at 5% Plant Cost per year			2,185			3,199			2,685	
(c) Taxes and Insurance at 2½% Plant Cost per year			1,092			1,599			1,342	
Sub-Total			7,647	0.435		11,195	0.541		9,397	0.483
3. Utilities:										
(a) Steam	24c/1000 Lbs.							16,400 Lbs./Hr.	94	
(b) Fuel	15c/10^6 BTU	195×10^6 BTU/Hr.	702		440×10^6 BTU/Hr.	1,584				
(c) Electrical Power	1.7c/KWH	2,055 KW	838		9,124 KW	3,722		1,895 KW	773	
(d) Water	2.5c/1000 US Gal.	14,200 GPM	511		34,100 GPM	1,288		25,120 GPM	904	
Sub-Total			2,051	0.117		6,594	0.318		1,771	0.091

4. Operating Personnel:										
(a) Foremen	$1.80/Hr.	2x24 Hrs.	86		1x24 Hrs.	43		1x24 Hrs.	43	
(b) Operators	$1.65/Hr.	23x24 Hrs.	911		22x24 Hrs.	871		12x24 Hrs.	475	
(c) Operator Helpers	$1.40/Hr.	16x24 Hrs.	538		32x24 Hrs.	1,075		17x24 Hrs.	571	
(d) Supervision	$600/Mo.	1 per day	20		1 per day	20		1 per day	20	
(e) Engineers	$500/Mo.	2 per day	33		3 per day	50		2 per day	33	
(f) Lab. and Office—Men	$300/Mo.	6 per day	60		7 per day	70		6 per day	60	
" " —Men	$200/Mo.	10 per day	67		10 per day	67		10 per day	67	
Sub-Total			1,715	0.098		2,196	0.106		1,269	0.065
5. Chemicals and Process Materials:										
(a) Diluent	$2.50/Bbl.	1,130 B/D	2,825	0.161	850 B/D	2,125				
(b) Soda Ash	2c/Lb.				2,108 Lbs./Hr.	1,012				
(c) Wetting Agent	35c/Lb.				70 Lbs./Hr.	588				
(d) Ball Mill Pebbles	$75/Ton				21.7 T/D	1,628				
Sub-Total						5,353	0.259			
6. Depreciation, Maintenance, Taxes, and Insurance on Auxiliaries (x)			1,800	0.102		3,080	0.149		2,430	0.125
A. Gross Processing Costs			16,741 (13,916)*	0.953 (0.792)*		29,246	1.413	15,647	0.804	
7. Credits:										
(a) Coke	10c/Ton	850 T/D	85		1,260 T/D	126				
(b) Net Steam Production	24c/1000 Lb.				90,000 Lbs./Hr.	518				
(c) Fuel Gas Production	15c/10^6 BTU							425x10^6 BTU/Hr.	1,530	
Sub-Total			85	0.005		644	0.031		1,530	0.078
B. Net Processing Costs			16,656 (13,831)*	0.948 (0.787)*		28,602	1.382		14,117	0.726

(x) Such as storage facilities, buildings, housing, site maintenance, medical and employee activities.
(*) Parentheses denote processing costs when no diluent is used in separation plant.

Unit costs shown for utilities, operating labor and processing materials are considered representative of those which might exist in Northern Alberta. Customary rates, based on refinery experience, were used for computing process plant costs and depreciation, maintenance, taxes and insurance. On the other hand item 6 in the Table representing depreciation, maintenance, taxes and insurance on ancillaries outside the battery limits was taken as about 7% per year on an investment of roughly $12,000,000 with slight adjustments for each of the alternate cases.

The possibility may be considered of dehydrating the bitumen from the hot water process before charging it to the fluidized coking unit. The reason for this proposal is that since an appreciable part of the volume of wet bitumen may be water, its dehydration prior to fluidized coking would permit the use of a smaller coking unit. A general study of this possibility has not indicated that any appreciable saving could be made.

Estimated costs for the desulphurization by mild hydrogenization of the fluidized coker distillate appear itemized in Table 22. Although the capital cost of this unit includes the initial charge of catalyst, no figure is shown in the operating cost summary for catalyst replacement since there is no life testing experience on which to base an estimate. In general catalyst replacement costs for hydrocarbon hydrogenation are a small item. Because the estimate was based on a limited amount of small experimental work, it is believed that the indicated cost might be reduced as experience is accumulated and more efficient techniques are applied in the hydrogenation step.

Costs shown previously for the production of a coker distillate and its desulphurization have been combined in Table 23 to show the total refining cost of preparing a desulphurized distillate from raw bituminous sand by the sequence of processing steps including—

A. Hot water separation of the bitumen

B. Fluidized solids coking of wet oil from A.

C. Desulphurization of the coker distillate from B.

This final overall refining cost amounts to $1.53 per barrel of desulphurized distillate.

SUMMARY OF PRODUCTION COSTS

The estimated operating costs arising from all the associated developments are included with the corresponding costs of the major developments mentioned in the tabulated processing and mining cost summary. The estimated capital cost of the ancillary developments has also been mentioned.

The Final Operating Costs are described as the costs per barrel of finished product. One cubic yard of the bituminous sand under consideration yields slightly more than one barrel of distillate by the sequence of processes selected.

The tabulation represents the total estimated cost per barrel of marketable product, commencing with the material in situ and continuing with all the processing and operations necessary for the delivery of the final product at the Great Lakes Terminal of the Canadian Pipe Line system.

The costs do not provide any payment for the raw material. The form and quality of this great resource are unique in a number of respects affecting the ultimate legislation for its control and disposal.

The estimates of costs do not take any credit that might arise from the by-product production of any of the minerals. The reason being that although sulphur production would be probably quite attractive, due to the availability of the separated hydrogen sulphide, the established market at present is probably limited to a quantity corresponding to the production from one project of this size.

The inclusion of credits, therefore, could lead to establishing an overall cost that would not be applicable to operations on an appreciably larger scale. The information is not yet sufficiently developed in regard to the other minerals present to determine the possibility of credits from them.

Table No. 22

COST OF HYDROGENATION (DESULPHURIZATION) OF FLUIDIZED COKER DISTILLATE

	No. of Units	Cost $/Day	$/Day Sub-Total	Cost $/Bbl. Product*
1. Administration, Overhead and Sales		990	990	0.050
2. Depreciation, Maintenance, Taxes and Insurance on Processing Unit:				
(a) Depreciation at 10% Plant Cost/Year		1,945		
(b) Maintenance at 5% Plant Cost/Year		973		
(c) Insurance and Taxes at 2½% Plant Cost/Year		486		
			3,404	0.172
3. Utilities:				
Steam—24c per 100 Lbs.	30,000 Lbs./Hr.	173		
Fuel—15c per 10^6 BTU.	54×10^6 BTU/Hr.	195		
Electric Power—1.7c per KWH.	9,800 KW	4,000		
Water—2.5c per 1,000 U.S. Gal.	3,000 U.S. GPM.	108		
			4,476	0.226
4. Personnel:				
Labor—Foreman—$1.80/Hr.	1x24 Hrs.	43		
Operators—$1.65/Hr.	1x24 Hrs.	40		
Helpers—$1.40/Hr.	3x24 Hrs.	100		
Supervision—$600/Mo.	1 per day	20		
Engineer—$500/Mo.	1 per day	17		
Laboratory and Office—Men—$300/Mo.	2 per day	20		
Men—$200/Mo.	2 per day	13		
			253	0.013
5. Processing Materials:				
Hydrogen—25c/1,000 cu. ft.	20 MM CFD	5,000	5,000	0.252
Catalyst Replacement	?	?	?	?
6. Depreciation, Maintenance, Taxes and Insurance on Auxiliary Equipment		1,980	1,980	0.100
TOTAL		16,103	16,103	0.813

* 19,800 B/D.

Table No. 23

SUMMARY OF COSTS FOR THE REFINING SEQUENCE

A. Hot Water Separation
B. Fluidized Coking of Wet Oil
C. Hydrogenation (Desulphurization) of Coker Distillate

	No. of Units	Cost $/Day	Sub-Total $/Day	Cost $/Bbl. Product*
1. Administration, Overhead and Sales		1,770	1,770	0.089
2. Depreciation, Maintenance, Taxes and Insurance on Processing Units:				
(a) Depreciation at 10% Plant Cost/Year		7,315		
(b) Maintenance at 5% Plant Cost/Year		3,658		
(c) Insurance and Taxes at 2½% Plant Cost/Year		1,828		
			12,801	0.646
3. Utilities:				
(a) Steam—24c per 1,000 Lbs.	46,400 Lbs./Hr.	267		
(b) Electrical Power—1.7c per KWH.	11,695 KW	4,773		
(c) Water—2.5c per 1,000 Gals.	28,120 GPM	1,012		
			6,052	0.306
4. Operating Personnel:				
(a) Foremen—$1.80/Hr.	2x24 Hrs.	86		
(b) Operators—$1.65/Hr.	13x24 Hrs.	515		
(c) Operator Helpers—$1.40/Hr.	20x24 Hrs.	671		
(d) Supervision—$600/Mo.	2 per day	40		
(e) Engineers—$500/Mo.	3 per day	50		
(f) Laboratory and Office, Men—$300/Mo.	8 per day	80		
Men—$200/Mo.	12 per day	80		
			1,522	0.077
5. Chemicals and Process Materials:				
(a) Hydrogen—25c/1,000 cu. ft.	20 MM CFD	5,000	5,000	0.252
(b) Catalyst Replacement	?	?	?	
6. Depreciation, Maintenance, Taxes and Insurance on Auxiliaries		4,410	4,410	0.222
A. GROSS PROCESSING COSTS			31,555	1.592
7. Credits—Fuel at 15c/10^6 BTU	371x10^6 BTU/Hr.	1,335	1,335	0.067
			30,220	1.525
B. NET PROCESSING COSTS			30,220	1.525

* 19,800 B/D Hydrogenated Liquid.

PRODUCTION COSTS

		$ Barrel Desulphurized Distillate
MINING—		
The mining costs are summarized on Page 54 and include the cost of the appropriate overburden removal for the location under consideration, the excavating, crushing, conveying, and any stockpiling necessary to permit continuous operation		$0.55
PROCESSING—		
The processing costs are summarized in Table No. 21 and 22 and include the costs from the delivery of the raw bituminous sands through the Hot Water Process, the Fluidizing Process, the Hydrogenation Desulphurizing Process, but excluding any major costs for oil transport		1.53
TRANSPORTATION—		
The transportation costs include:		
(a) An allowance for transport from the field to Edmonton	$0.28	
(b) The pipeline tariff from Edmonton to the Great Lakes Terminal	.55	
(c) An allowance for the cost of storage and all other transportation expenses additional to the direct line costs	.19	1.02
The Total Production Cost per barrel of desulphurized coker distillate at the Great Lakes Terminal of the Canadian Pipeline		$3.10

REVIEW OF THE ESTIMATED REALIZATION AND THE PRODUCTION COST

The study has developed a realization of at least $3.50 per barrel and a total production cost for the same product at the same place of $3.10 per barrel.

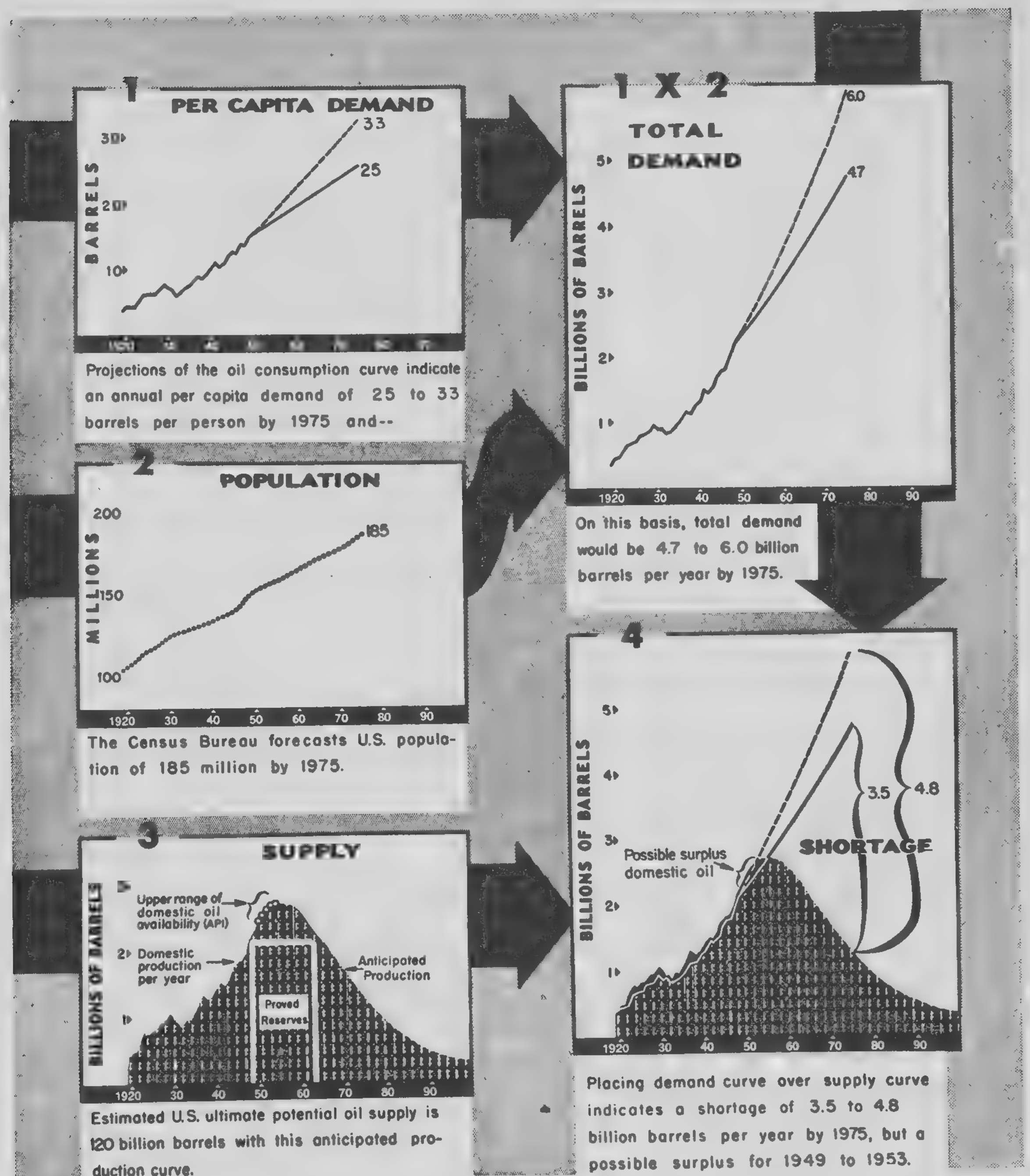
The results thus indicate that it is now possible with a sequence of suitable plants of adequate size to mine and process bitumen to marketable oils at a total direct operating cost that is at least $0.40 per barrel less than the probable realization. Further if the same relationship exists between the price of No. 2 Fuel and Crudes in the future potential markets for this oil that has existed between them previously in the United States, then the forty cents difference might be very materially increased.

The price of $3.50 is believed to be sufficiently low to permit subsequent operations to make a satisfactory profit with market prices of the present order. The $3.10 estimated total production cost includes $1.02 for transport operating costs, which may be considered as being on a basis that provides a satisfactory profit directly on the capital involved. No specific allowance however, has been included in the Processing and Mining Costs totalling $2.08 for interest or profit on the capital.

A capital expenditure has been indicated for the initial mining equipment of approximately $2,000,000. The total estimated capital expenditure for the Processing Plants exclusive of ancillary equipment is $29,600,000. On the basis that none of the ancillary developments costing $12,000,000 are profit earning, then the total capital expenditure is $43,600,000 on which interest and profit is required. It may be noted that on the basis used and with an annual operation of 300 days (6,000,000 barrel production), the 40¢ per barrel profit would yield between 5% and 6% on the capital concerned.

The graphs showing the relationship between crude oil and No. 2 Fuel prices also illustrate the direct increase in the magnitude of market values over the past fifteen and particularly in the past five years. Whether the bituminous sand development with its unavoidable basic costs for mining and processing could have shown a possible economic operation when crude prices were about one-half what they are now seems doubtful. It will be noted, however, that all development costs would have been materially lower then than the present costs used in these estimates. Considering the bitumen evaluation on a wide perspective of prices, those used here do not appear to be abnormally high on the basis of the current surveys.

The future demand and order of oil prices is, of course, of major importance in any consideration of the development of the bituminous sands. The estimated reserves of crude have been recorded for the oil industry, and it is of interest to note the results of the survey of the U.S. Bureau of Mines on the future position. The Bureau has given a very clear summary in graph 24. The charts are very self-explanatory and prepared to illustrate the present and estimated conditions in the United States during the next 25 years. The graphs clearly illustrate the enormous increase that is taking place in the demand for all fuels as well as the inevitable fall-off that must ultimately be experienced in normal oil reserves. The recent demand on the Canadian oil market has shown an even greater rate of consumption increase than that in the United States.

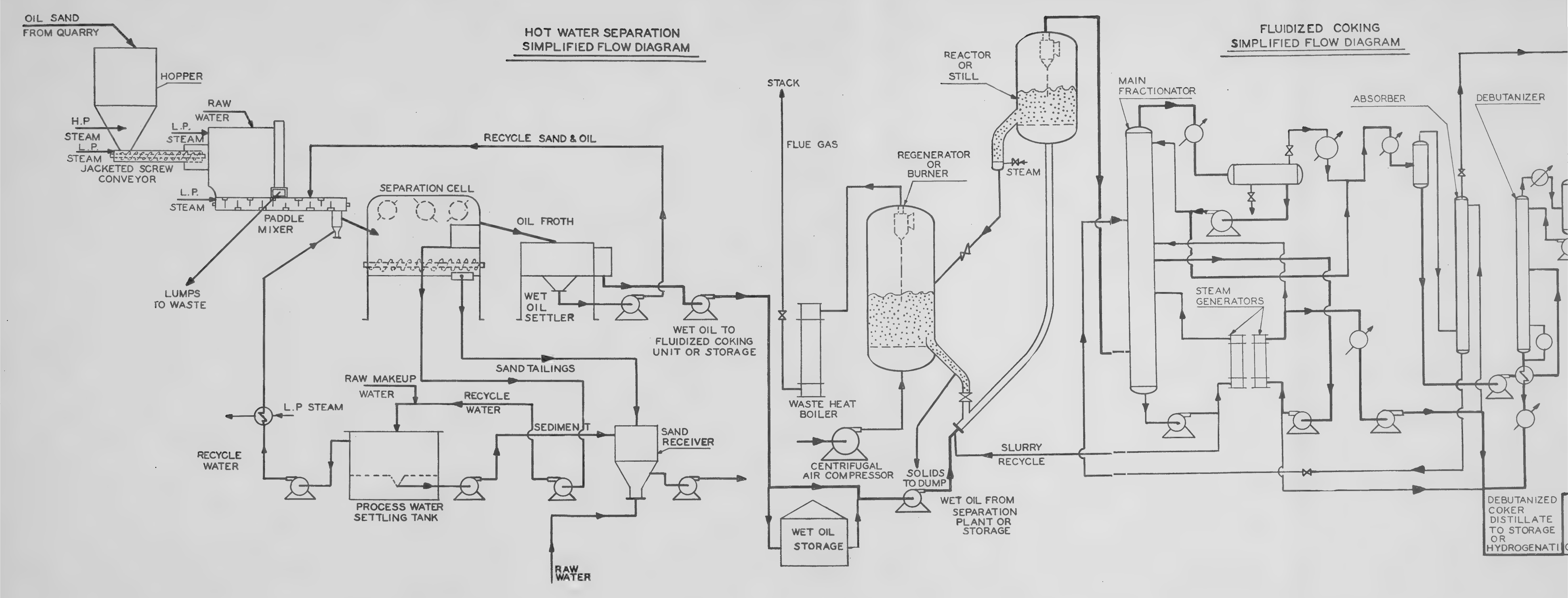


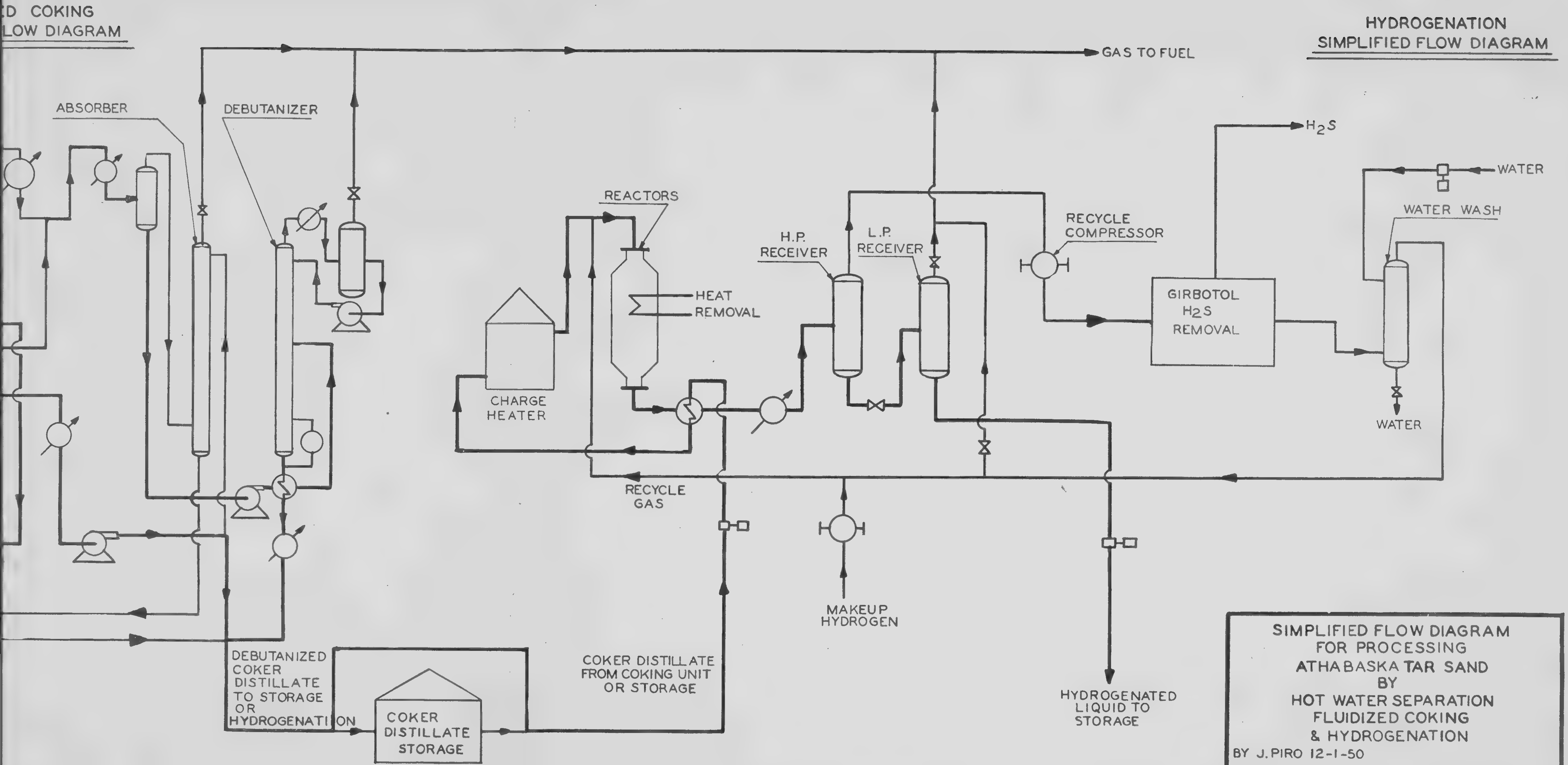
U.S. OIL PROBLEM

FIGURE 24

Solution to Future Shortage:—
- Synthetic Liquid Fuels
- Greater Imports
- Secondary Recovery
- Tidelands Oil

U.S. Bureau of Mines
(OSLF), Apr., 1949


HOT WATER SEPARATION
SIMPLIFIED FLOW DIAGRAM
OIL SAND
FROM QUARRY
HOPPER
H.P
STEAM
L.P.
STEAM
JACKETED SCREW
CONVEYOR
RAW
WATER
L.P.
STEAM
L.P.
STEAM
PADDLE
MIXER
LUMPS
TO WASTE
RECYCLE SAND & OIL
SEPARATION CELL
OIL FROTH
WET
OIL
SETTLER
WET OIL TO
FLUIDIZED COKING
UNIT OR STORAGE
SAND TAILINGS
RAW MAKEUP
WATER
RECYCLE
WATER
SEDIMENT
SAND
RECEIVER
L.P STEAM
RECYCLE
WATER
PROCESS WATER
SETTLING TANK
RAW
WATER
FLUIDIZED COKING
SIMPLIFIED FLOW DIAGRAM
STACK
FLUE GAS
WASTE HEAT
BOILER
REGENERATOR
OR
BURNER
REACTOR
OR
STILL
STEAM
CENTRIFUGAL
AIR COMPRESSOR
SOLIDS
TO DUMP
WET OIL
STORAGE
WET OIL FROM
SEPARATION
PLANT OR
STORAGE
SLURRY
RECYCLE
MAIN
FRACTIONATOR
STEAM
GENERATORS
ABSORBER
DEBUTANIZER
DEBUTANIZED
COKER
DISTILLATE
TO STORAGE
OR
HYDROGENATI



SIMPLIFIED FLOW DIAGRAM
FOR PROCESSING
ATHABASKA TAR SAND
BY
HOT WATER SEPARATION
FLUIDIZED COKING
& HYDROGENATION

BY J. PIRO 12-1-50
JOB P-6490 W.O. 25102 DWG. 50793-NK

The fact that the quality of the crude bitumen, its near surface occurrence, and the technique that is required for its initial processing are all different from those experienced with normal crude oil has led, at times, to its being classified with oil shales and coals as a potential future fuel. This general assumption can lead to very erroneous conclusions both technically and economically.

The investigations of quality have now shown that the components are not similar to those from oil shale or coal. The response of the components to refining corresponds more closely to those of normal crudes. For example, the gas oil catalytically cracks to the same type of products, and order of yields as is obtained from Mid-Continent gas oils. The relationship now determined between costs and probable realizations based on standard crude oil markets, shows that the economies also of producing marketable oils from this source correspond with the economics of the oil industry.

An important economic factor in the study of bitumen-oil production is the relationship of quality to its transportation costs. Oil from that remote district will attract total transportation costs of from $1.00 to possibly $1.50 before delivery to a major Eastern market. Transportation costs of that order represent an appreciably bigger percentage of the selling price than is experienced by some of the major centers of production that might compete with oils from that area. In view of this an oil such as that which will be made from the bitumen and is free of the low price fuel components of normal crude oils has an appreciable transport cost advantage over lower priced crudes.

A comparison of the economics of normal oil and bitumen-oil production shows a number of important contrasts. The lack of processing history is very obvious in the case of the bitumen and is difficult to appraise. In the case of bitumen production the ease of proof of availability of raw material and the complete assurance of charging stock for greatly enlarged Plants to almost any extent could result in very material savings. In this survey a capacity is assumed of 20,000 barrels per day since that permits the use of a reasonably sized economical plant. Much smaller developments following the same sequence will experience appreciably higher costs, while much larger developments, which as mentioned would have no problem of securing raw feed, could operate at lower costs particularly in regard to the overhead and general administration costs.

SUMMARY OF CHAPTER III

1. The compilation of the estimated Mining costs by Open Pit operation of $0.55 per cubic yard of bituminous sand in the selected area, and of the capital cost of the initial equipment for that type of operation of $1,930,000 are shown.
2. The methods by which the capital and operating costs for the processing units have been developed are described.
3. The selected sequence of processes chosen are Open Pit mining; Hot Water Separation; Fluidized Distillation; Desulphurization by Mild Hydrogenation, followed by Marketing.
4. The merits of producing bitumen for non-fuel purposes, such as Road Oils, Carbon Black, and Gas Production are reviewed.
5. The possibility of producing a raw, high sulphur gas oil at one-half the anticipated direct processing cost is considered.
6. The quality of oil that would be secured by desulphurizing the fluidized distillate is stated and fully tabulated.
7. The possible means of evaluating the desulphurized distillate are each examined.
8. The value of the whole product on catalytically cracking the gas oil portion in the Chicago area, crediting the products and debiting the operating costs at Chicago prices, results in a value of $4.03 per barrel at the refinery.
9. The quality of the gas oil is shown to be very similar to No. 2 Furnace Fuel.
10. Examination of the relationship of No. 2 Fuel to corresponding crude prices over some fifteen years for the Mid-Continent, Texas, and Illinois oils shows the No. 2 Fuel is priced at about one-third above the price of crude.

11. Considering the relationship of gas oil to crude prices, and assuming Redwater Crude Oil worth \$3.00 per barrel at Superior, and also noting the Chicago realization for the gas oil and adjusting the price to Superior, it is considered that the distillate is worth at least \$3.50 per barrel at Superior.

12. The processing cost determinations are tabulated and shown to total \$1.525 per barrel.

13. The pertinent capital costs are tabulated and described.

14. The total production costs per barrel of distillate delivered at Superior is determined as \$3.10.

15. No value is placed on the raw material.

16. No credit is taken for possible by-product production such as sulphur.

17. The possibility of a greater difference than 40¢ between realization and direct operating costs is referred to.

18. The magnitude of capital expenditure and the present possible return on capital is mentioned.

19. The future oil prices and requirements are reviewed and the findings of the U.S. Department of Mines noted.

20. Attention is drawn to the error of considering the production of Bituminous Sands either technically or economically as corresponding to production from Oil Shale or Coal.

21. The basic advantage which the production of a valuable oil such as this desulphurized distillate has over crude oils when produced in a remote area with unavoidable high transport costs is noted.

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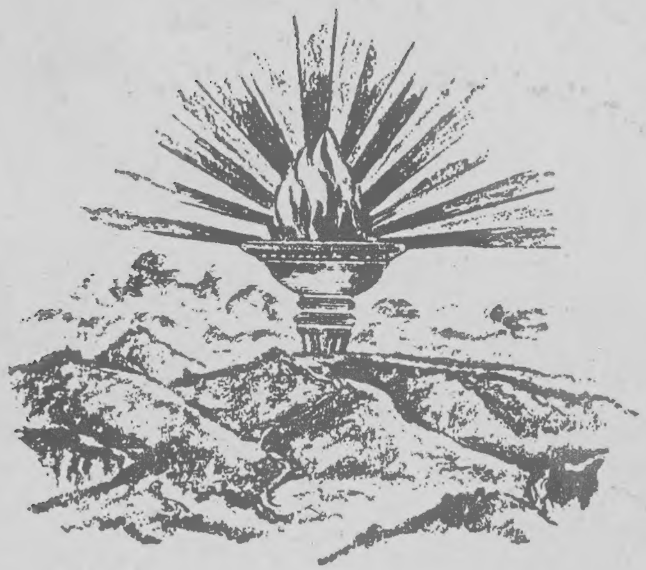

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